Appendix A. Input Data and Parameters

LIST OF TABLES

The following table itemizes the variables, data inputs, parameters, and indices employed in each of the Transportation Model's constituent components. These variables are grouped by module, and are identified by the equation number in Appendix B in which they are first encountered. The sources of parameters and data inputs are provided immediately following this table.

Table A-1. List of Transportation Sector Model Variables

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model					
ITEM	**CLASS. (Source)**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ACTUAL$MKT	Variable	The economic share of technology *itc*, prior to consideration of engineering or regulatory constraints.	Percent	FEMCALC	10
ADJFE	Variable	The fuel economy adjustment factor	Percent	FEMCALC	24
ADJHP	Variable	The fractional change in horsepower from the previous year within a given vehicle class	Percent	FEMCALC	22
BENCHMPG	Input Data (B)	MPG benchmark factors to ensure congruence with most recent data from NHTSA	–	FEMSIZE	45
CAFE	Variable	Actual CAFE values by group	Miles per Gallon	CAFECALC	37
CLASS$SHARE	Variable	Relative market share for each class. Basis for CAFE calculations	Percent	CAFECALC	36
CMKS	Variable	Class market share, subsequently reassigned to the appropriate vehicle class and group, $CLASS\$SHARE_{icl,igp}$	Percent	CMKSCALC	35
COSTEF$FUEL	Variable	Cost effectiveness based on fuel savings	–	FEMCALC	6
COSTEF$PERF	Variable	Cost effectiveness based on performance	–	FEMCALC	7
DEL$COSTABS	Variable	Change in cost associated with technology *itc*	Percent	FEMCALC	4
DEL$COSTWGT	Variable	The weight-based change in cost of technology *itc*	$ per lb	FEMCALC	4
DEL$FE	Variable	The fractional change in fuel economy associated with technology *itc*	Percent	FEMCALC	3
DEL$HP	Variable	The fractional change in horsepower of technology *itc*	Percent	FEMCALC	5
DEL$MKT	Variable	The amount of the superseded technology's market share to be removed	Percent	NOTE$SUPER	29
DEL$WGTABS	Variable	The change in weight associated with technology *itc*	lbs	FEMCALC	16
DEL$WGTWGT	Variable	The fractional change in weight associated with technology *itc*	Percent	FEMCALC	4
DELTA$MKT	Variable	The change in market share for technology *itc*	Percent	FEMCALC	17

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model					
ITEM	**CLASS. (Source)**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
DIFF$LN	Variable	The increment from the historical calibrated year of the log of the market share ratio	–	CMKSCALC	32
DISCOUNT	Parameter (A)	Discount rate used in payback calculation	Percent	FEMCALC	3
FE	Variable	Fuel economy of technology *itc*, within seven size classes	Miles per Gallon	FEMCALC	3
FEMPG	Variable	Average fuel economy by six ORNL size classes	MPG	FEMSIZE	44
FESIXC	Variable	Fuel economy for cars within six size classes	MPG	FEMSIZE	46
FESIXT	Variable	Fuel economy for light trucks within six size classes	MPG	FEMSIZE	46
FUELCOST	Variable	Projected fuel cost	$ per MMBtu	FEMCALC	1
FUELSAVE	Variable	The expected present value of fuel savings over the payback period	$	FEMCALC	3
HP	Variable	Horsepower	HP	FEMCALC	21
icl	Index	FEM vehicle size class index (7)	–	FEMSIZE	–
igp	Index	CAFE group index: 1 = domestic car, 2 = import car, 3 = domestic light truck, 4 = import light truck	–	FEMSIZE	–
INCOME	Variable	Household income	$ per year	FEMCALC	22
ino	Index	The index identifying the technologies in the superseding group	–	NOTE$SUPER	–
isno	Index	An index indicating the superseded technology	–	NOTE$SUPER	–
itc	Index	The index representing the technology under consideration	–	FEMCALC	3
MANDMKSH	Input Data (A)	Mandatory market share	Percent	FEMCALC	12
MAP	Input Data (A)	Array of mapping constants, which converts FEM to ORNL size classes	–	FEMSIZE	41
MAPSALE	Variable	Disaggregate vehicle sales	Units	FEMSIZE	41
MAPSHR	Variable	Sales shares within the disaggregate array	Percent	FEMSIZE	43
MAX$SHARE	Input Data (A)	The maximum market share of the group, *ino*	Percent	NOTE$SUPER	28
MKT$MAX	Input Data (A)	Maximum market share of technology in given class	Percent	NOTE$SUPER	28
MKT$PEN	Variable	Market share of technology in given class and year	Percent	FEMCALC	11
MMAX	Variable	The maximum market share for technology *itc*, obtained from MKT$MAX	Percent	FEMCALC	10
N	Index	Time period index (1990 = 1)	–	FEMSIZE	–

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model					
ITEM	**CLASS. (Source)**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
num$sup	Index	The number of technologies in the superseding group	–	NOTE$SUPER	–
NVS7SC	Variable	New vehicle sales within the seven FEM size classes	Units	TSIZE	47
ORNLMPG	Input Data (B)	Most recent (1992) fuel economy data from ORNL	MPG	FEMSIZE	45
osc	Index	ORNL size class index (6)	–	FEMSIZE	–
PAYBACK	Input Data (A)	The user-specified payback period	Years	FEMCALC	3
PERFFACT	Input Data (A)	Performance factor (multiplier for horsepower adjustment)	–	FEMCALC	22
PMAX	Parameter (A)	The institutional maximum market share, which models tooling constraints on the part of the manufacturers	Percent	FEMCALC	10
PRICE	Variable	Vehicle price	$	FEMCALC	20
PRICE$EX	Variable	The expected price of fuel	$	FEMCALC	2
PSLOPE	Variable	The fuel cost slope	–	FEMCALC	1
RATIO$LN	Variable	Log of the market share ratio of the considered vehicle class	–	CMKSCALC	34
REGCOST	Variable	A factor representing regulatory pressure to increase fuel economy	$ per MPG	FEMCALC	6
REQ$MKT	Input Data (A)	The total market share of those technologies which are required for the implementation of technology *itc*, indicating that technology's maximum share	Percent	FEMCALC	13
SYNR$DEL	Input Data (A)	The synergistic effect of two technologies on fuel economy	–	FEMCALC	16
TECHCOST	Input Data (A)	The cost of technology *itc*	$	FEMCALC	4
TOT$MKT	Variable	The total market share of the considered group of technologies	Percent	NOTE$SUPER	30
TOTNVS7	Variable	Total new vehicle sales within the six ORNL size classes	Units	FEMSIZE	42
VAL$PERF	Input Data (A)	The dollar value of performance of technology *itc*	$	FEMCALC	5
VALUEPERF	Variable	The value associated with an incremental change in performance	$	FEMCALC	5
WEIGHT	Variable	The base year vehicle weight, absent the considered technology	lbs	FEMCALC	4
YEAR	Index	Year index (*YEAR* = *N*+1)	–	FEMSIZE	–

LIGHT DUTY VEHICLE MODULE: Regional Sales Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AHPCAR	Variable	Average automobile horsepower	HP	TSIZE	55
AHPTRUCK	Variable	Average light truck horsepower	HP	TSIZE	56
COMTSHR	Data Input (B)	Fraction of new light trucks dedicated to commercial freight	Percent	TSIZE	48
COSTMIR	Variable	The cost of driving in region *REG*	$ per Mile	TREG	58
DAF	Paramete r (C)	A demographic adjustment factor, to reflect different age groups' driving patterns	—	TEXOG	61
FLTCRAT	Paramete r (B)	Fraction of new cars purchased by fleets	Percent	TSIZE	47
FLTTRAT	Paramete r (B)	Fraction of new light trucks purchased by fleets	Percent	TSIZE	48
GROUP	Index	Index indicating domestic or imported vehicles	—	TSIZE	—
HP	Variable	Vehicle horsepower by FEM size class, group	HP	TSIZE	53
HPCAR	Variable	Average horsepower of new automobiles, by size class *SC*	HP	TSIZE	53
HPTRUCK	Variable	Average horsepower of new light trucks, by size class *SC*	HP	TSIZE	54
INCOMER	Variable	Regional per capita disposable income	$	TREG	59
LTSHRR	Variable	Non-fleet market shares of light trucks, by size class *SC*	Percent	TSIZE	52
NCS	Variable	New car sales, by size class and region	Units	TREG	63
NCSTSCC	Variable	New car sales in the modified six size classes, *SC*	Units	TSIZE	49
NLTS	Variable	New light truck sales, by size class and region	Units	TREG	64
NLTSTSCC	Variable	New light truck sales in six size classes *SC*	Units	TSIZE	50
NVS7SC	Variable	New vehicle sales in the original seven FEM size classes	Units	TSIZE	47
PASSHRR	Variable	Non-fleet market shares of automobiles, by size class *SC*	Percent	TSIZE	51

LIGHT DUTY VEHICLE MODULE: Regional Sales Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
PRFEM	Data Input (D)	Ratio of female to male driving rates	—	TVMT	60
RHO	Paramete r (C)	Lag factor for the VMT difference equation	—	TVMT	60
RSHR	Variable	Regional VMT shares	Percent	TREG	62
SALESHR	Data Input (B)	Fraction of vehicle sales which are domestic/imported	Percent	TSIZE	47
SEDSHR	Variable	Regional share of the consumption of a given fuel in period *T*	Percent	TREG	57
TMC_POP16	Variable	Total regional population over the age of 16	—	TMAC	61
TMC_POPAFO	Variable	Total population in region *REG*	—	TMAC	59
TMC_SQDTRU CKS	Variable	Total light truck sales (supplied by the MACRO module)	Units	TMAC	48
TMC_SQTRCA RS	Variable	Total new car sales (supplied by the MACRO module)	Units	TSIZE	47
TMC_YD	Variable	Estimated disposable personal income by region, *REG*	$	TMAC	57
VMT16R	Variable	Vehicle-miles traveled per population over 16 years of age	—	TREG	60
VMTEER	Variable	Total VMT in region *REG*	—	TREG	61

LIGHT DUTY VEHICLE MODULE: Alternative Fuel Vehicle Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTIN E**	**EQ #**
ACCL	Variable	Acceleration time from 0-30 mph	seconds	TALT2	69
ACCL1	Variable	Acceleration time from 0-30 mph	seconds	TALT1	73
APSHR11	Variable	Relative market shares of each aggregate technology	Percent	TALT1	75
APSHR22	Variable	Relative market shares of each AFV technology	Percent	TALT2	71
APSHR44	Variable	Absolute market shares of each technology	Percent	TALT1	76
BETAFA	Parameter (F)	Coefficient associated with fuel availability	–	TALT1 & TALT3	69,73
BETAFA2	Parameter (F)	Coefficient associated with the square of fuel availability	–	TALT1 & TALT3	69,73
CALIB	Input data	Calibration factor added to gasoline vehicles to match historical AFV sales in 1998	_	TALT1	73
CAVL	Input Data (E)	Commercial availability of each AFV technology	–	TALT1 & TALT3	65,74
DR200	Variable	Dummy variable for gasoline capable vehicle with range greater than 200 miles	0,1	TALT2	69
DR2001	Variable	Dummy varialbe for gasoline capable vehicle with range greater than 200 miles	0,1	TALT1	73
DR250	Variable	Dummy variable for gasoline capable vehicle with range greater than 250 miles	0,1	TALT2	69
DR2501	Variable	Dummy variable for gasoline capable vehicle with range greater than 250 miles	0,1	TALT1	73
EVC1	Variable	Exponentiated value of vehicle utility vector	–	TALT1	74
EVC2	Variable	Exponentiated value of alternative vehicle utility vector	–	TALT2	70
FAVL	Input Data (E)	Availability of each alternative fuel relative to gasoline	Percent	TALT2	68
FAVL1	Input Data (E)	Fuel availability for conventional and alternative technologies	Percent	TALT1	73
FLCOST	Variable	Fuel operating cost	Nominal $ per Mile	TALT2	67
FLCOST1	Variable	Fuel operating cost	Nominal $ per Mile	TALT1	73
HFUEL	Variable	Dummy variable for home refueling for EV's	0,1	TALT2	69
HFUEL1	Variable	Dummy variable for home refueling for EV's	0,1	TALT1	73
IT	Index	Index of the sixteen engine technologies considered by the model	–	TALT1 & TALT2	–
LUGG	Input Data	Luggage space indexed to gasoline vehicle	0 to 1	TALT2	69
LUGG1	Input Data	Luggage space indexed to gasoline vehicle	0 to 1	TALT1	73
MAINT	Input Data	Maintenance cost and battery replacement cost	Nminal $/yr	TALT2	69

LIGHT DUTY VEHICLE MODULE: Alternative Fuel Vehicle Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTIN E**	**EQ #**
MAINT1	Input Data	Maintenance cost and battery replacement cost	Nminal $/yr	TALT1	73
MFUEL	Variable	Dummy variable for multi-fuel capability	0,1	TALT2	69
MFUEL1	Variable	Dummy variable for multi-fuel capability	0,1	TALT1	73
PSPR	Variable	Vehicle price for technology (based on cost)	Nominal $	TALT2	69
PSPR1	Variable	Vehicle price for technology (based on cost)	Nominal $	TALT1	73
RFP	Variable	Regional fuel price	Dollars per MMBtu	TALT2	66
RGT250	Variable	Vehicle range in excess of 250 miles	miles	TALT2	69
RGT2501	Variable	Vehicle range in excess of 250 miles	miles	TALT1	73
TPSD	Variable	Top speed of vehicle	mph	TALT2	69
TPSD1	Variable	Top speed of vehicle	mph	TALT1	73
TT50	Input Data (X)	The exogenously specified year in which 50% of the demand for technology *IT* can be met	Year	TALT2	65
VC1	Variable	Utility vector for conventional and alternative vehicles	–	TALT1	73
VC2	Variable	Utility vector for alternative vehicles	–	TALT2	69
VRNG	Variable	Vehicle range of the dedicated fuel technologies	Miles	TALT2	69
VRNG1	Variable	Vehicle range of the dedicated fuel technologies	Miles	TALT1	73

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ADJVMTPC	Variable	Demographically-adjusted per capita VMT	Vehicle-miles	TVMT	156
AMPGC	Variable	The average MPG of cars within the reduced AFV size class	Miles per gallon	TMPGSTK	141
AMPGT	Variable	The average MPG of trucks within the reduced AFV size class	Miles per gallon	TMPGSTK	141
ANCMPG	Variable	Average new car MPG	Miles per gallon	TMPGSTK	145
ANTMPG	Variable	Average new light truck MPG	Miles per gallon	TMPGSTK	145
APSHRNC	Variable	Absolute market share of new cars, by technology, from the AFV model	Percent	TMPGSTK	145
APSHRNT	Variable	Absolute market share of new light trucks, by technology, from the AFV model	Percent	TMPGSTK	145
ASC	Index	The three AFV size classes, onto which the six primary size classes are mapped	–		–
CCMPGLDV	Variable	New car MPG, by technology *IT*	MPG	TMPGAG	179
CMPGSTK	Variable	Automobile stock MPG, by vintage and technology	Miles per gallon	TMPGSTK	147
CMPGT	Variable	Automobile stock MPG	Miles per gallon	TMPGSTK	147
COSTMI	Variable	Cost of driving per mile	$ per mile	TVMT	151
DAF	Input Data (C)	Demographic adjustment factor	–	TVMT	156
FLTECHSAL	Variable	Fleet sales by size, technology, and fleet type	Units	TMPGAG	167
FLTECHSALT	Variable	Vehicle purchases by fleet type and technolgy	Units	TMPGAG	167
FLTECHSTK	Variable	Total fleet vehicle stock, by technology and fleet type	Units	TMPGAG	169
FLTMPG	Variable	Fleet vehicle MPG by vehicle type, size class, and technology	MPG	TMPGAG	168
FLTMPGNEW	Variable	New fleet vehicle MPG, by vehicle type and technology *ITECH*	MPG	TMPGAG	168
FLTSTOCK	Variable	New fleet stock, by vehicle type and technology *ITECH*	Units	TMPGAG	169
FLTVMT	Variable	Fleet VMT	Vehicle-miles	TVMT	158
FLVMTSHR	Variable	VMT-weighted shares by size class and technology	Percent	TFREISMOD	162
FVMTSC	Variable	Freight VMT by size class	Vehicle-miles	TVMT	158
INCOME	Variable	Per capita disposable personal income	$	TVMT	152
IS	Index	Index of size class (1-3)	–	TMPGAG	–
IT	Index	Index of vehicle technology (1-16)	–	TMPGAG	–

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
IT2	Index	Reassigned indices of vehicle technology *IT2* = 1-16; *IT* = 16,15,1-14	–	TMPGAG	–
ITECH	Index	Index of fleet vehicle technologies which correspond to the *IT* index	–	TMPGAG	–
ITY	Index	Index of fleet type: Business, Government, Utility	–	TMPGAG	–
LTSTK	Variable	Surviving light truck stock, by technology and vintage	Units	TSMOD	132
LVMT	Variable	Average light truck VMT, by vintage, from RTECS	Vehicle miles traveled	TEXOG	146
MPGC	Variable	New car fuel efficiency, by engine technology	Miles per gallon	TMPGSTK	143
MPGC	Variable	New car MPG, by technology *IT*	MPG	TMPGAG	170
MPGFLT	Variable	Stock MPG for all light duty vehicles	Miles per gallon	TMPGSTK	151
MPGT	Variable	New light truck fuel efficiency, by engine technology	Miles per gallon	TMPGSTK	143,171
MPGTECH	Variable	Average stock MPG by technology	MPG	TMPGSTK	150
NCMPG	Variable	New car MPG, from the FEM model	Miles per gallon	TMPGSTK	141
NCS3A	Variable	New car sales by reduced size class and engine technology: *IS* = 1, *OSC* = 1,6; *IS* = 2, *OSC* = 2,3; *IS* = 3, *OSC* = 4,5	Units	TMPGSTK	137
NCS3SC	Variable	Total new car sales by reduced size class	Units	TMPGSTK	139
NCSR	Variable	Regional new car sales by reduced size class	Units	TMPGSTK	138
NCSTECH	Variable	New car sales, by region, size class, and technology, from the AFV Module	Units	TSMOD	131
NLT3A	Variable	New light truck sales by reduced size class and technolgy: *IS* = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6	Units	TMPGSTK	137
NLTECH	Variable	New light truck sales, by region, size class, and technology	Units	TSMOD	131
NLTMPG	Variable	New light truck MPG, from the FEM model	Miles per gallon	TMPGSTK	141
NLTS3SC	Variable	Total new light truck sales by reduced size class	Units	TMPGSTK	139
NLTSR	Variable	Regional new light truck sales by reduced size class	Units	TMPGSTK	138
NNCSCA	Variable	New conventional car sales by six size classes	Units	TMPGSTK	140
NNLTCA	Variable	New conventional light truck sales by six size classes	Units	TMPGSTK	140

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
OLDFSTK	Variable	Number of fleet vehicles rolled over into corresponding private categories	Units	TSMOD	134
PASSTK	Variable	Surviving automobile stock, by technology and vintage	Units	TSMOD	132
PrFem	Data Input (C)	The ratio of per capita female driving to per capita male driving.	—	TVMT	141
PVMT	Variable	Average automobile VMT, by vintage, from RTECS	Vehicle miles traveled	TEXOG	146
RATIO	Variable	Light truck MPG adjustment factor	—	TMPGSTK	142
RHO	Parameter (C)	Difference equation lag factor, estimated, using the Cochrane-Orcutt iterative procedure, to be 0.72	—	TVMT	153
SCMPG	Variable	Stock MPG for automibles	Miles per gallon	TMPGSTK	148
SSURVLT	Input Data (B)	Fraction of a given vintage's light trucks which survive	Percent	TSMOD	133
SSURVP	Input Data (B)	Fraction of a given vintage's automobiles which survive	Percent	TSMOD	133
STKCAR	Variable	Total stock of non-fleet automobiles in year *T*	Units	TSMOD	135
STKCT	Variable	Stock of non-fleet vehicles, by technology	Units	TMPGAG	158
STKTR	Variable	Total stock of non-fleet light trucks in year *T*	Units	TSMOD	135
STMPG	Variable	Stock MPG for light trucks	Miles per gallon	TMPGSTK	148
STOCKLDV	Variable	Total stock of fleet and non-fleet vehicles, by technology	Units	TMPGAG	172
TECHNCS	Variable	Non-fleet new car sales, by technology *IT*	Units	TMPGAG	170
TECHNCS	Variable	Total new car sales, by technology	Units	TSMOD	131
TECHNLT	Variable	Total new light truck sales, by technology	Units	TSMOD	131
TECHNLT	Variable	Non-fleet new light truck sales, by technology *IT*	Units	TMPGAG	171
TLDVMPG	Variable	Average fuel economy of light-duty vehicles	MPG	TMPGAG	175
TMC_POPAFO	Variable	Total population, from MACRO module	Units	TVMT	152
TMC_SQDTRUCKSL	Variable	Total light truck sales, from MACRO module	Units	TFREISMOD	161
TMC_YD	Variable	Total disposable personal income, from MACRO module	$	TVMT	152
TMPGLDVSTK	Variable	Average MPG by vehicle type *VT*	MPG	TMPGAG	174
TMPGT	Variable	Light truck stock MPG	Miles per gallon	TMPGSTK	148
TOTMICT	Variable	Total miles driven by cars	Miles	TMPGSTK	146
TOTMITT	Variable	Total miles driven by light trucks	Miles	TMPGSTK	146

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
TPMGTR	Variable	Price of motor gasoline	$ per gallon	TVMT	151
TRFLTMPG	Variable	Average light truck MPG	MPG	TFREISMOD	166
TRSAL	Variable	Light truck sales for freight	Units	TFREISMOD	161
TRSALTECH	Variable	Light truck sales by technology	Units	TFREISMOD	162
TRSTK	Variable	Total light truck stock	Units	TFREISMOD	165
TRSTKTECH	Variable	Light truck stock by technology	Units	TFREISMOD	163
TRSTKTOT	Variable	Total light truck stock by technology	Units	TFREISMOD	164
TSTOCKLDV	Variable	Total stock by vehicle type *VT*	Units	TMPGAG	173
TTMPGLDV	Variable	New light truck MPG, by technology *IT*	MPG	TMPGAG	171
TTMPGSTK	Variable	Light truck stock MPG, by vintage and technology	Miles per gallon	TMPGSTK	147
VDF	Input Data (N)	Vehicle fuel efficiency degradation factor	Percent	TMPGSTK	147
VMTECH	Variable	Personal travel VMT by technology	Vehicle-miles	TVMT	159
VMTEE	Variable	VMT for personal travel	Vehicle-miles	TVMT	158
VMTLDV	Variable	Total VMT for light duty vehicles	Vehicle-miles	TVMT	157
VSPLDV	Variable	The light duty vehicle shares of each of the sixteen vehicle technologies	Percent	TSMOD	136
VT	Index	Index of vehicle type: 1 = cars, 2 = light trucks	–	TMPGAG	–
XLDVMT	Variable	Fractional change of VMT over base year (1990)	Percent	TVMT	160

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
APSHR55	Variable	Absolute regional market shares of adjusted vehicle sales	Percent	TLEGIS	101
APSHRFLTB	Variable	Market shares of business fleet by vehicle type and technology	Percent	TLEGIS	106
APSHRFLTB	Variable	Alternative technology shares for the business fleet	Percent	TLEGIS	84
APSHRFLTOT	Variable	Aggregate market shares of fleet vehicle technologies	Percent	TLEGIS	105
APSHRNC	Variable	Market shares of new cars by technology	Percent	TLEGIS	104
APSHRNT	Variable	Market shares of new light trucks by technology	Percent	TLEGIS	104
AVSALES	Variable	Regional adjusted vehicle sales by size class	Units	TLEGIS	97
AVSALEST	Variable	Total regional adjusted vehicle sales by size class	Units	TLEGIS	100
DEL_TECH	Variable	Sum of all the additional vehicle sales from scaling up hybrid and fuel cell vehicles to meet the maximum allowable ZEV credits	Units	TLEGIS	132
ELECVSAL	Variable	Regional electric vehicle sales	Units	TLEGIS	92
ELECVSALSC	Variable	Regional ZEV sales within corresponding regions	Units	TLEGIS	96
EPACT	Parameter (H)	Legislative mandates for AFV purchases, by fleet type	Percent	TEXOG	81
FLTALT	Variable	Number of AFV's purchased by each fleet type in a given year	Units	TFLTSTKS	81
FLTAPSHR1	Input Data (G)	Fraction of each fleets' purchases which are AFV's, from historical data	Percent	TEXOG	81
FLTCONV	Variable	Fleet purchases of conventional vehicles	Units	TFLTSTKS	82
FLTCRAT	Input Data (G)	Fraction of total car sales attributed to fleets	Percent	TEXOG	80
FLTCSHR	Input Data (G)	Fraction of fleet cars purchased by a given fleet type	Percent	TEXOG	80
FLTECH	Variable	Vehicle purchases by fleet type and technology	Units	TFLTSTKS	85
FLTECHSAL	Variable	Fleet sales by size, technology, and fleet type	unts	TFLTSTKS	84
FLTECHSHR	Input Data (G)	Alternative technology shares for the government and utility fleets	Percent	TEXOG	84
FLTFCLDVBTU	Variable	Fuel consumption by vehicle type and technology	MMBtu	TFLTCONS	117
FLTFCLDVBTUR	Variable	Regional fuel consumption by fleet vehicles, by technology	MMBtu	TFLTCONS	118
FLTLDVC	Variable	Fuel consumption by technology, vehicle and fleet type	MMBtu	TFLTCONS	116
FLTMPG	Variable	New fleet vehicle fuel efficiency, by fleet type and engine technology	Miles per Gallon	TFLTMPG	110

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FLTMPGTOT	Variable	Overall fuel efficiency of new fleet cars and light trucks	MPG	TFLTMPG	112
FLTSAL	Variable	Sales to fleets by vehicle and fleet type	Units	TFLTSTKS	80
FLTSLSCA	Variable	Fleet purchases of AFV's, by size class	Units	TFLTSTKS	83
FLTSLSCC	Variable	Fleet purchases of conventional vehicles, by size class	Units	TFLTSTKS	83
FLTSSHR	Input Data (G)	Percentage of fleet vehicles in each size class, from historical data	Percent	TEXOG	83
FLTSTKVN	Variable	Fleet stock by fleet type, technology, and vintage	Units	TFLTSTKS	86
FLTTOTMPG	Variable	Fleet vehicle average fuel efficiency for cars and light trucks	Miles per Gallon	TFLTMPG	115
FLTTRAT	Input Data (G)	Fraction of total truck sales attributed to fleets	Percent	TEXOG	80
FLTTSHR	Input Data (G)	Fraction of fleet trucks purchased by a given fleet type	Percent	TEXOG	80
FLTVMT	Variable	Total VMT driven by fleet vehicles	Vehicle Miles Traveled	TFLTVMTS	108
FLTVMTECH	Variable	Fleet VMT by technology, vehicle type, and fleet type	Vehicle Miles Traveled	TFLTVMTS	109
FLTVMTYR	Variable	Annual miles of travel per vehicle, by vehicle and fleet type	Miles	TFLTVMTS	108
FMSHC	Variable	The market share of fleet cars, from the AFV model	Percent	TFLTMPG	110
FMSHLT	Variable	The market share of fleet light trucks, from the AFV model	Percent	TFLTMPG	110
IR	Index	Corresponding regions: *ST* = CA, MA, NY; *IR* = 9,1,2	–	TLEGIS	–
IS	Index	Index of size classes: 1 = small, 2 = medium, 3 = large	–	TFLTSTKS	–
ITECH	Index	Index of engine technologies: 1-5 = alternative fuels (neat), 6 = gasoline	–	TFLTSTKS	–
ITF	Index	Index of fleet vehicle technologies, corresponding to *IT* = 3,5,7,8,9	–	TLEGIS	–
ITY	Index	Index of fleet type: 1 = business, 2 = government, 3 = utility	–	TFLTVMTS	–
MAXVINT	Index	Maximum *IVINT* index associated with a given vehicle and fleet type	–	TFLTMPG	–
MPGFLTSTK	Variable	Fleet MPG by vehicle and fleet type, and technology, across vintages	Miles per Gallon	TFLTMPG	114
MPGFSTK	Variable	Fleet MPG by vehicle and fleet type, technology, and vintage	Miles per Gallon	TFLTMPG	113

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
NAMPG	Variable	New AFV fuel efficiency, from the AFV model	Miles per Gallon	TALT3	110
NCSTECH	Variable	Regional new car sales by technology, within six size classes: *OSC* = 1-6; *IS* = 2,1,1,3,3,2	Units	TLEGIS	107
NLTECH	Variable	Regional light truck sales by technology, with six size classes: *OSC* = 1-6; *IS* = 1,2,1,3,2,3	Units	TLEGIS	107
OLDFSTK	Variable	Old fleet stocks of given types and vintages, transferred to the private sector	Units	TFLTSTKS	87
QBTU	Input Data (I)	Energy content of the fuel associated with each technology	Btu/Gal	TFLTCONS	117
RSHR	Variable	Regional VMT shares, from the Regional Sales Module	Percent	TREG	118
ST	Index	Index of participating state: CA, MA, NY	–	TLEGIS	–
STATESHR	Variable	Share of national vehicle sales attributed to a given state	Percent	TLEGIS	94
SURVFLTT	Input Data (G)	Survival rate of a given vintage	Percent	TFLTSTKS	86
TFLTECHSTK	Variable	Total stock within each technology and fleet type	Units	TFLTSTKS	88
TMC_SQDTRUCKSL	Variable	Total light truck sales in a given year	Units	TMAC	80
TMC_SQTRCARS	Variable	Total automobile sales in a given year	Units	TMAC	80
TOTCRED	Variable	Total available ZEV credits from either hybrid or fuel cell vehicles	Units	TLEGIS	128
TOTFLTSTK	Variable	Total of all surviving fleet vehicles	Units	TFLTSTKS	89
TZEVSAL	Variable	Total ZEV sales of hydrogen fuel cell and dedicated electric vehicles	Units	TLEGIS	130
ULEV	Data Input (J)	State-mandated minimum sales share of ULEV's	Percent	TLEGIS	94
ULEVST	Variable	State-mandated minimum sales of ULEV's	Units	TLEGIS	94
VFSTKPF	Variable	Share of fleet stock by vehicle type and technology	Percent	TFLTSTKS	90
VSALES	Variable	Total disaggregate vehicle sales	Units	TLEGIS	91
VSALES_EV	Variable	Sales of electric vehicles	Units	TLEGIS	128
VSALES_EVGH	Variable	Sales of electric gasoline hybrid vehicles	Units	TLEGIS	127
VSALES_EVDH	Variable	Sales of electric diesel hybrid vehicles	Units	TLEGIS	128
VSALES_FCG	Variable	Sales of fuel cell gasoline vehicles	Units	TLEGIS	128
VSALES_FCH	Variable	Sales of fuel cell hydrogen vehicles	Units	TLEGIS	128
VSALES_FCM	Variable	Sales of fuel cell methanol vehicles	Units	TLEGIS	128
VSALESC16	Variable	Total new car sales by technology: *IS* = 1, *OSC* = 2,3; *IS* = 2, *OSC* = 1,6; *IS* = 3, *OSC* = 4,5	Units	TLEGIS	103

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
VSALEST	Variable	Total regional vehicle sales, by size class	Units	TLEGIS	93
VSALEST16	Variable	Total new light truck sales by technology: *IS* = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6	Units	TLEGIS	103
VT	Index	Index of vehicle type: 1 = cars, 2 = light trucks	–	TFLTSTKS	–
ZEV	Data Input (J)	State-mandated minimum sales share of ZEV's	Percent	TLEGIS	94
ZEVST	Variable	State-mandated minimum sales of ZEV's	Units	TLEGIS	94
ZEVSTSC	Variable	Mandated ZEV sales by size class and state	Units	TLEGIS	95

AIR TRAVEL MODULE: Air Travel Demand Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
DI	Parameter (O)	Demographic air travel index, reflecting public's propensity to fly	—	TAIRT	239
EQSM	Input Data (O)	Equivalent seat-miles conversion factor; used to transform freight RTMs to seat-miles	—	TAIRT	242
LFDOM	Parameter (O)	Load factor, the average fraction of seats which are occupied in domestic travel.	Percent	TAIRT	242
LFINTER	Parameter (O)	Load factor for international travel.	Percent	TAIRT	242
PCTINT	Parameter (O)	Proportionality factor relating international to domestic travel levels	—	TAIRT	236
RPMB	Variable	Revenue passenger miles of domestic travel for business purposes.	Passenger Miles	TAIRT	238
RPMBPC	Variable	Per capita domestic RPM for business travellers.	Miles per Capita	TAIRT	234
RPMD	Variable	Total domestic revenue passenger miles.	Passenger Miles	TAIRT	241
RPMI	Variable	Revenue passenger miles of international travel.	Passenger Miles	TAIRT	240
RPMIPC	Variable	Per capita international RPM	Miles per Capita	TAIRT	236
RPMP	Variable	Revenue passenger miles of domestic travel for personal purposes.	Passenger Miles	TAIRT	239
RPMPPC	Variable	Per capita domestic RPM for personal travel.	Miles per Capita	TAIRT	235
RTM	Variable	Revenue ton miles of cargo.	Ton Miles	TAIRT	237
SMDEMD	Variable	Total seat-miles demanded for domestic and international travel	Seat Miles	TAIRT	242
TPJFTR	Variable	Price of Jet Fuel.	Dollars per Gallon	TMAC	233
YIELD	Variable	Airline revenue per passenger mile	Dollars per Passenger-Mile	TAIRT	233

AIR TRAVEL MODULE: Aircraft Fleet Efficiency Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AGD	Variable	Demand for aviation gasoline, in gallons	Gallons	TAIREFF	261
AGDBTU	Variable	Aviation gasoline demand, in Btu	Btu	TAIREFF	262
AIRHRS	Input Data (P)	Average number of airborne hours per aircraft, by type.	Hours per Year	TAIREFF	243
ASMDEMD	Variable	Demand for available seat-miles, by aircraft type	Seat Miles	TAIREFF	245
ASMP	Variable	The available seat-miles per plane, by type	Seat Miles	TAIREFF	243
AVSPD	Input Data (P)	Average flight speed, by type.	Miles per Hour	TAIREFF	243
BASEAGD	Parameter	Baseline demand for aviation gasoline	Gallons	TAIREFF	261
BASECONST	Parameter	Baseline constant, used to anchor the technology penetration curve	–	TAIREFF	254
COSTFX	Parameter	Factor reflecting the magnitude of the difference between the price of jet fuel and the trigger price of the considered technology	–	TAIREFF	253
DELTA	Parameter	User-specified rate of passenger shifts between aircraft types	–	TAIREFF	244
EFFIMP	Input Data (P)	Fractional improvement associated with a given technology	Percent	TAIREFF	256
FRACIMP	Variable	Fractional improvement over base year (1990) fuel efficiency, by type	Percent	TAIREFF	257
GAMMA	Parameter (P)	Baseline adjustment factor	–	TAIREFF	261
IFX	Index	Index of technology improvements (1-6)	–	TAIREFF	–
IT	Index	Index of aircraft type: 1 = narrow body, 2 = wide body	–	TAIREFF	–
IVINT	Index	Index of aircraft vintage	–	TAIREFF	–
IYEAR	Index	Current year	–	TAIREFF	–
JFBTU	Variable	Jet fuel demand, in Btu	Btu	TAIREFF	262
JFGAL	Variable	Consumption of jet fuel, in gallons	Gallons	TAIREFF	262
KAPPA	Parameter (P)	Exogenously-specified decay constant	–	TAIREFF	261
NEWSMPG	Variable	Average seat-miles per gallon of new aircraft purchases	SMPG	TAIREFF	257
NPCHSE	Variable	Number of aircraft purchased, by body type.	Aircraft	TAIREFF	248
NSURV	Variable	Number of surviving aircraft, by body type.	Aircraft	TAIREFF	250
QAGR	Variable	Regional demand for aviation gasoline	Btu	TAIREFF	263
QJETR	Variable	Regional demand for jet fuel	Btu	TAIREFF	263
RHO	Parameter (P)	Average historic rate of growth of fuel efficiency	–	TAIREFF	258

AIR TRAVEL MODULE: Aircraft Fleet Efficiency Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
SEAT	Input Data (P)	Average number of seats per aircraft, by type.	Seats per Aircraft	TAIREFF	243
SMFRACN	Variable	Fraction of seat-mile demand on narrow-body planes	Percent	TAIREFF	244
SMPG	Variable	Average seat miles per gallon for new purchases and surviving fleet, by type.	Seat Miles per Gallon	TAIREFF	258
SMPGT	Variable	Overall fleet average seat-miles per gallon	SMPG	TAIREFF	259
SMSURV	Variable	Surviving travel capacity by body type.	Seat Miles	TAIREFF	247
SSURVPCT	Parameter (P)	Marginal survival rate of planes of a given vintage	Percent	TAIREFF	246
STKOLD	Variable	Fraction of planes older than one year, by aircraft type	Percent	TAIREFF	251
SURVK	Parameter (P)	User-specified proportionality constant	–	TAIREFF	246
SURVPCT	Input Data (P)	Survival rate of planes of a given vintage *IVINT*	Percent	TAIREFF	246
T50	Parameter (P)	User-specified vintage at which stock survival is 50%	Years	TAIREFF	246
TIMECONST	Parameter (P)	User-specified scaling constant, reflecting the importance of the passage of time	–	TAIREFF	252
TIMEFX	Parameter (P)	Factor reflecting the length of time an aircraft technology improvement has been commercially viable	–	TAIREFF	252
TOTALFX	Parameter (P)	Overall effect of fuel price and time on implementation of technology *IFX*	–	TAIREFF	254
TPJFGAL	Variable	Price of jet fuel	$ per Gallon	TAIREFF	253
TPN	Variable	Binary variable (0,1) which tests whether current fuel price exceeds the considered techology's trigger price	–	TAIREFF	253
TPZ	Variable	Binary variable which tests whether implementation of the considered technology is dependent on fuel price	–	TAIREFF	253
TRIGPRICE	Parameter (P)	Price of jet fuel above which the considered technology is assumed to be commercially viable	$ per Gallon	TAIREFF	253
TYRN	Variable	Binary variable which tests whether current year exceeds the considered technology's year of introduction	–	TAIREFF	253
XAIREFF	Variable	Fractional change in aircraft fuel efficiency from base year	Percent	TAIREFF	264

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ANNVMTBASE	Input Data (B)	Base year average annual VMT per vehicle.	–	TRANFRT	199
ANNVMT	Variable	Average annual VMT per vehicle.	Vehicle miles	TRANFRT	199
AVGPRC	Variable	Average price of fuel over three years period	$	TRANFRT	176
CAPCXG	Parameter	Endogenously determined capital cost of a technology	–	TRANFRT	177
COALT	Variable	Ton miles of travel of coal production	Ton-miles	TRAIL	216
COALD	Variable	Distance of coal travel by region	Miles	TRAIL	216
COALP	Variable	Production of coal by region east/west	Ton	TRAIL	216
COEFAFV	Parameter	Endogenously determined logistic market penetration curve parameter	–	TRANFRT	186
COEFFAC	Parameter	Endogenously determined logistic decay curve parameter	–	TRANFRT	201
COEFT	Parameter	Endogenously determined logistic market penetration curve parameter	–	TRANFRT	178
DISCRTXG	Parameter	Endogenously determined discount rate used to calculate a trigger price	–	TRANFRT	177
FACTR	Function	Freight Adjustment Coefficient–relates growth in value added in industry I to growth in freight transportation	Percent	TRANFRT	201
FCOST	Variable	Fuel cost of driving a truck	Dollars per mile	TRANFRT	184
FERAIL	Input Data (B)	Rail fuel efficiency	Miles per gallon	TRAIL	220
FESHIP	Input Data (B)	Domestic freighter fuel efficiency	–	TSHIP	226
FSHR	Variable	Actual market share of fuel technology	Percent	TRANFRT	189
FUEL	Variable	Total truck fuel consumption by sector, size class, vintage, fuel, and fleet	Gallons of gasoline eq	TRANFRT	212
GROSST	Variable	Value of gross trade (imports + exports)	$	TSHIP	229
HTRATE	Input Data (I)	Heat content of fuel used by each technology	MMBtu per gallon	TRANFRT	213
IFUEL	Index	Index of fuel type	–	TRANFRT	–
INITYR	Variable	Year in which technology TECH enters market	YEAR	TRANFRT	177
ISC	Index	Index of truck size class (1-3)	–	TRANFRT	–
ISEC	Index	Place holder for industry group	–	TFREI	–
ISFD	Variable	International freighter energy demand, by fuel	MMbtu	TSHIP	230
ISFDT	Variable	Total international shipping energy demand	MMBtu	TSHIP	229

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ITECH	Index	Index of engine technology (1-5)	–	TRANFRT	–
MIDYR	Variable	Endogenously determined logistic market penetration curve parameter	Year	TRANFRT	178
MPATH	Variable	Share of diesel in conventional truck sales	Percent	TRANFRT	187
MPG	Variable	Truck fuel efficiency by class, vintage, and fuel type	Mile per gallon	TRANFRT	183
MPGDEGFAC	Variable	Fuel economy degradation factor	Percent	TRANFRT	211
MPGEFF	Variable	Total effect of all fuel-saving technologies on new truck economy	Percent	TRANFRT	182
MYRAFV	Parameter	Logistic market penetration curve parameter representing halfway point to maximum market penetration	–	TRANFRT	186
OUTPUT	Variable	Value of output of each industry in base year dollars.	Dollars	TFREI	202
PAYBKXG	Parameter	Endogenously determined payback period used to calculate a trigger price.	–	TRANFRT	177
PREFF	Variable	Effect of fuel price on market penetration rates for six fuel-saving technologies	Percent	TRANFRT	179
PVMT	Variable	Perceived total VMT demand for trucks	Vehicle miles	TRANFRT	207
PVMTBASE	Variable	Baseline for Perceived demand for freight VMT to be calculated	Vehicle miles	TRANFRT	204
PVMTDMD	Variable	Perceived demand for freight VMT	Vehicle miles	TRANFRT	205
PVMTGROWTH	Variable	Perceived growth rate for demand for freight VMT	Percent	TRANFRT	203
PVMTUNMET	Variable	Difference between perceived and actual demand for freight VMT	Vehicle miles	TRANFRT	206
PVN	Variable	Annual VMT per vehicle	Vehicle miles	TRANFRT	208
RCOST	Variable	Fuel cost per mile of diesel relative to LPG and CNG	Percent	TRANFRT	185
RTMT	Variable	Total rail freight traffic, by industry	Ton Miles	TRAIL	217
RTMTT	Variable	Total rail ton-miles traveled	Ton Miles	TRAIL	219
SEDSHR	Parameter (K)	Regional shares of shipping fuel demand	Percent	TFREI	228
SFD	Variable	Domestic freighter energy demand, by fuel	MMBtu	TSHIP	227
SFDBENCH	Parameter (I)	Benchmark factor to ensure congruence with 1990 data	–	TSHIP	226
SFDT	Variable	Domestic freighter energy demand	MMBtu	TSHIP	226
SFSHARE	Parameter (B)	Domestic shipping fuel allocation factor	–	TSHIP	227
STMT	Variable	Total waterborne freight traffic, by industry	Ton Miles	TSHIP	224

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
STMTT	Variable	Total ship ton-miles traveled	Ton Miles	TSHIP	225
TECH	Variable	Fuel-saving technology	Percent	TRANFRT	180
TECHSHR	Variable	Market share of fuel-saving technology	Percent	TRANFRT	180
TGPRCXG	Variable	Trigger price; price at which a technology is cost effective	–	TRANFRT	177
TQISHIPR	Variable	Total regional energy demand by international freighters	MMBtu	TSHIP	231
TQRAIL	Variable	Total demand for each fuel by rail freight sector in year *T*	MMBtu	TRAIL	221
TQRAILR	Variable	Total regional rail fuel consumption for each technology	MMBtu	TRAIL	222
TQRAILT	Variable	Total energy consumption by freight trains in year *T*	MMBtu	TRAIL	220
TQSHIPR	Variable	Total regional energy demand by domestic freighters, by fuel type	MMBtu	TSHIP	228
TRF1	Variable	Number of trucks transferred from fleet to non-fleet, if no restrictions are placed on the transfer of alternative-fuel trucks	Number of trucks	TRANFRT	193
TRF2	Variable	Number of trucks transferred from fleet to non-fleet, if the fuel mix of fleet transfer is exactly the same as the fuel mix of new non-fleet purchases	Number of trucks	TRANFRT	194
TRF	Variable	Total number of trucks transferred from fleet to non-fleet	Number of trucks	TRANFRT	195
TRFSHR	Variable	Share of fleet transfers which goes to each sector	Percent	TRANFRT	196
TRILL	Variable	Truck fuel consumption by secotr, size class, fuel type, and fleet	MMBTu	TRANFRT	213
TRKSTK	Variable	Number of trucks by sector, size class, vintage, fuel type, and fleet	Number of trucks	TRANFRT	197
TSIC	Variable	Value of output of industry *I*, in base year (1990) dollars	$	TRAIL	217
VMT	Variable	Actual VMT by trucks	Vehicle miles	TRANFRT	210
VMTDMD	Variable	Actual VMT demand	Vehicle miles	TRANFRT	202
VMTOLD	Variable	VMT that is meet by existing truck stock	Vehicle miles	TRANFRT	200
VMTTREND	Variable	VMT index growth per truck	Percent	TRANFRT	198
XRAIL	Variable	Growth in rail travel from base year	Percent	TRAIL	223
XRAILEFF	Variable	Growth in rail efficiency from base year	Percent	TRAIL	223
XSHIP	Variable	Growth in ship travel from base year	Percent	TSHIP	232
XSHIPEFF	Variable	Growth in ship efficiency from base year	Percent	TSHIP	232

MISCELLANEOUS ENERGY DEMAND MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
BETALUB	Parameter (K)	Coefficient of proportionality, relating highway travel to lubricant demand	–	TMISC	276
BETAMS	Parameter (B)	Coefficient of proportionality, relating mass transit to LDV travel	–	TMISC	268
BETAREC	Parameter (B)	Coefficient of proportionality relating income to fuel demand for boats	–	TMISC	272
FLTVMT	Variable	Total fleet vehicle VMT, from the Fleet Module	Vehicle Miles	TFLTVMTS	275
FMPG	Variable	Fuel efficiency for mass transit vehicles, by vehicle type, from the Freight Module	Miles per gallon	TFREI	269
FMPG89	Data Input (B)	Base-year fuel efficiency for mass transit vehicles, by vehicle type, from the Freight Module	Miles per gallon	TEXOG	269
FTVMT	Variable	Total freight truck VMT, from the Freight Module	Vehicle Miles	TMISC	274
FVMTSC	Variable	Freight truck VMT, by size class		TMISC	274
HYWAY	Variable	Total highway VMT	Vehicle Miles	TMISC	275
IF	Index	Index of fuel type: 1=Distillate, 2=Naphtha, 3=Residual, 4=Kerosene	–	TMISC	–
IM	Index	Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail	–	TMISC	–
IM	Index	Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail		TMISC	–
LUBFD	Variable	Total demand for lubricants in year T	MMBtu	TMISC	276
MFD	Variable	Total military consumption of each fuel in year T	MMBtu	TMISC	266
MILTARGR	Variable	The growth in the military budget from the previous year	Percent	TMISC	265
MILTRSHR	Input Data (L)	Regional consumption shares, from 1991 data, held constant	Percent	TMISC	267
QLUBR	Variable	Regional demand for lubricants in year T	MMBtu	TMISC	277
QMILTR	Variable	Regional military fuel consumption, by fuel type	MMBtu	TMISC	267
QMODR	Variable	Regional consumption of fuel, by mode	MMBtu	TMISC	271
QRECR	Variable	Regional fuel consumption by recreational boats in year T	MMBtu	TMISC	273
RECFD	Variable	National recreational boat gasoline consumption in year T	MMBtu	TMISC	272
TMC_GFML87	Variable	Total defense budget in year T, from the macro economic segment of NEMS	$	TMAC	265
TMC_POPAFO	Variable	Regional population forecasts, from the Macro Module	People	TMAC	271
TMC_YD	Variable	Total disposable personal income, from the Macro Module	$	TMAC	272

MISCELLANEOUS ENERGY DEMAND MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
TMEFF89	Input Data (B)	Base-year Btu per vehicle-mile, by mass transit mode	Btu per vehicle mile	TMISC	269
TMEFFL	Variable	Btu per passenger-mile, by mass transit mode	Btu per passenger mile	TMISC	269
TMFD	Variable	Total mass-transit fuel consumption by mode	Gallons	TMISC	270
TMOD	Variable	Passenger-miles traveled, by mode	Passenger miles	TMISC	268
TMLOAD89	Data Input (B)	Average passengers per vehicle, by mode, held constant at 1989 values (1=LDV's)	Units	TMISC	268
TYPE	Index	Vehicle type, from the Freight Module: 1 = Mid-size trucks, 2 = Rail	–	TFREI	269
VMTEE	Variable	LDV vehicle-miles traveled, from the VMT module	Vehicle miles	TVMT	268

TRANSPORTATION EMISSIONS MODULE

ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
EFACT	Parameter (M)	Emissions factor relating measures of travel to pollutant emissions	–	TEMISS	278
EMISS	Variable	Regional emissions of a given pollutant, by mode of travel	Tons per year	TEMISS	278
IE	Index	Index of pollutants: 1 = SO_x, 2 = NO_x, 3 = C, 4 = CO_2, 5 = CO, 6 = VOC	–	TEMISS	278
IM	Index	Index of travel mode: references individual vehicle types used in the preceding modules	–	TEMISS	278
IR	Index	Index identifying census region	–	TEMISS	278
U	Variable	Measure of travel demand, by mode: units in VMT for highway travel, gallons of fuel consumption for other modes	–	TEMISS	278

SOURCES OF DATA INPUTS AND PARAMETERS USED IN THE NEMS TRANSPORTATION MODEL

CODE	SOURCE
A	*Conventional Light-Duty Vehicle Fuel Economy*, Decision Analysis Corporation of Virginia and Energy and Environmental Analysis, Inc., Prepared For: Energy Information Administration, U.S. Department of Energy, Washington D.C., November, 1992.
B	*Transportation Energy Data Book: Edition 12*, Oak Ridge National Laboratory, Prepared For: Office of Transportation Technologies, U.S. Department of Energy, Washington, D.C., March 1992.
C	*Revised VMT Forecasting Model*, Unpublished Memorandum, U.S. Department of Energy, February 22, 1993.
D	*1990 National Personal Transportation Survey*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., March 1992.
E	*Alternative-Fuel Vehicle Module*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
F	*Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey*, D. S. Bunch, *et. al.,* University of California, Davis, UCD-ITS-RR-91-14, December 1991.
G	*Fleet Vehicles in the United States*, Oak Ridge National Laboratories, Prepared For: Office of Transportation Technologies and Office of Policy, Planning and Analysis, U.S. Department of Energy, Washington, D.C., March 1992.
H	*Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector; Technical Report Ten: Analysis of Alternative-Fuel Fleet Requirements*, Office of Domestic and International Energy Policy, U.S. Department of Energy, May 1992.
I	*Annual Energy Outlook 1993*, Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, D.C., January 1993.
J	*Proposed Regulations for Low-Emission Vehicles and Clean Fuels*, State of California Air Resources Board, August 13, 1990.
K	*State Energy Data Survey 1991*, Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, Washington, D.C., May 1993.
L	*Fuel Oil and Kerosene Sales 1991*, Energy Information Administration, Office of Oil and Gas, U.S. Department of Energy, Washington D.C., November 1992.
M	*Emissions Regulations, Inventories, and Emission Factor for the NEMS Transportation Energy and Research Forecasting Model*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
N	*Fuel Efficiency Degradation Factor*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1992.
O	*Proposed Methodology for Projecting Air Transportation Demand*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., July 1992.
P	*Preliminary Estimation of the NEMS Aircraft Fleet Efficiency Module*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
Q	*Freight Transportation Requirements Analysis for the NEMS Transportation Sector Model*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1992.

Table A-2. Light Duty Vehicle Market Classes

CLASS	DEFINITION	EXAMPLE MODEL
AUTOMOBILES (Domestic and Import)		
Minicompact	Interior passenger volume < 79 ft^3	Geo Metro, Toyota Paseo (no domestic cars)
Subcompact	Passenger volume between 79 ft^3 and 89 ft^3	Nissan Sentra, Honda Civic, GM Saturn, Ford Escort
Sports	Two door high performance cars costing less than $25,000	VW Corrado, Honda Prelude, Chevy Camaro, Ford Mustang
Compact	Passenger volume between 89 and 95 ft^3	Honda Accord, Toyota Camry, Ford Tempo, Pontiac Grand Am
Intermediate	Passenger volume between 96 and 105 ft^3	Nissan Maxima, Ford Taurus, Chevy Lumina
Large	Passenger volume >105 ft^3	Ford Crown Victoria, Pontiac Bonneville (no imports)
Luxury	Cars over $25,000	Lincoln Continental, Cadillac, all Mercedes, Lexus LS400
LIGHT TRUCKS (Domestic and Import)		
Compact Pickup	Trucks with inertia weight between 2750 and 4000 lbs.	All import trucks, Ford Ranger, GM S-10/15
Compact Van	Vans with inertia weight between 3000 and 4250 lbs.	All import vans, Plymouth, Voyager, Ford Aerostar
Compact Utility	Utility vehicles with inertia weight between 3000 and 4250 lbs.	Nissan Pathfinder, Toyota SR-5, Ford Bronco II, Jeep Cherokee
Standard Pickup	Trucks with inertia weight over 4000 lbs.	GM C-10, Ford F-150 (no imports)
Standard Van	Vans with inertia weight over 4250 lbs.	GM C15 van, Ford E-150 (no imports)
Standard Utility	Utility vehicles with inertia weight over 4250 lbs.	Toyota Land Cruiser, GM Suburban, Ford Blazer
Mini-truck	Utility/trucks below 2750 lbs. inertia weight	Suzuki Samurai (no domestics)

Table A-3. Maximum Light Duty Vehicle Market Penetration Parameters

Old Market Share	**New PMAX (Automobiles)**	**New PMAX (Light Trucks)**
≤ 1%	1%	1%
1.1-2%	2%	2%
2.1-3%	5%	5%
3.1-6%	12%	10%
6.1-10%	28%	22%
10.1-12%	32%	26%
12.1-14%	36%	30%
14.1-17%	41%	35%
17.1-20%	47%	40%
20.1-24%	53%	47%
24.1-27%	56%	50%
27.1-31%	60%	54%
31.1-35%	64%	58%
35.1-40%	68%	62%
40.1-45%	73%	67%
45.1-53%	78%	73%
53.1-62%	83%	79%
62.1-73%	88%	85%
73.1-85%	94%	92%
85.1-100%	100%	100%

Table A-4. Aircraft Fleet Efficiency Model Adjustment Factors

Year	DI	PCTINT
1979	0.974	0.27
1980	0.976	0.32
1981	0.978	0.30
1982	0.980	0.28
1983	0.982	0.27
1984	0.985	0.28
1985	0.988	0.28
1986	0.991	0.25
1987	0.994	0.28
1988	0.996	0.30
1989	0.998	0.33
1990	1.000	0.35
1991	1.003	0.38
1992	1.004	0.40
1993	1.005	0.41
1994	1.007	0.42
1995	1.008	0.43
1996	1.007	0.44
1997	1.007	0.45
1998	1.006	0.46
1999	1.006	0.46
2000	1.005	0.47
2001	1.003	0.47
2002	1.001	0.48
2003	0.998	0.48
2004	0.996	0.48
2005	0.994	0.48
2006	0.992	0.49
2007	0.989	0.49
2008	0.987	0.49
2009	0.985	0.49
2010	0.983	0.49
2011	0.980	0.49
2012	0.978	0.49
2013	0.975	0.50
2014	0.972	0.50
2015	0.970	0.50
2016	0.967	0.50
2017	0.965	0.50
2018	0.962	0.50
2019	0.960	0.50
2020	0.957	0.50
2021	0.956	0.50
2022	0.954	0.50
2023	0.952	0.50
2024	0.951	0.50
2025	0.949	0.50
2026	0.948	0.50
2027	0.946	0.50
2028	0.944	0.50
2029	0.943	0.50
2030	0.941	0.50

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Appendix C. Model Abstract

Model Name:

Transportation Sector Model

Model Acronym:

TRAN

Description:

The Transportation Sector Model incorporates an integrated modular design which is based upon economic, engineering, and demographic relationships that model transportation sector energy consumption at the nine Census Division level of detail. The Transportation Sector Model comprises the following components: Light Duty Vehicles, Light Duty Fleet Vehicles, Commercial Light Trucks, Freight Transport (truck, rail, and marine), Aircraft, Miscellaneous Transport (military, mass transit, and recreational boats), and Transportation Emissions. The model provides sales estimates of 2 conventional and 14 alternative-fuel light duty vehicles, and consumption estimates of 12 main fuels.

Purpose of the Model:

As a component of the National Energy Modeling System integrated forecasting tool, the transportation model generates mid-term forecasts of transportation sector energy consumption. The transportation model facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact transportation sector energy consumption.

Most Recent Model Update:

October, 1999.

Part of Another Model?

National Energy Modeling system (NEMS).

Model Interfaces:

Receives inputs from the Electricity Market Module, Oil and Gas Market Module, Renewable Fuels Module, and the Macroeconomic Activity Module.

Official Model Representative:

David Chien
Energy Information Administration
Office of Integrated Analysis and Forecasting
Energy Demand and Integration Division
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EI-84, Room 2F-094
Washington, DC 20585
Telephone: (202) 586-3994

Documentation:

Model Documentation Report: Transportation Sector Model of the National Energy Modeling System, DOE/EIA-M070(00),January, 2000.

Archive Media and Installation Manual(s):

The model will be archived on IBM tape compatible with the IBM RS6000 mainframe system upon completion of the NEMS production runs to generate the Annual Energy Outlook 2000.

Energy System Described:

Domestic transportation sector energy consumption.

Coverage:

- Geographic: Nine Census Divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific.
- Time Unit/Frequency: Annual, 1990 through 2020.
- Products: Motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG, methanol, ethanol, hydrogen, lubricants, pipeline fuel natural gas.
- Economic Sectors: Forecasts are produced for personal and commercial travel, freight trucks, railroads, domestic and international marine, aviation, mass transit, and military use.

Model Interfaces:

Model outputs are provided to the Integrating Module, which then sends them back to the supply modules.

Model Structure:

Light-duty vehicles are classified according to the six EPA size classes for cars and light trucks. Freight trucks are divided into medium-duty and heavy-duty size classes. Buses are subdivided into commuter, intercity, and school buses. The air transport module contains both wide- and narrow-body aircraft. Rail transportation is composed of freight rail and three modes of personal rail travel: commuter, intercity and transit. Shipping is divided into domestic and international categories.

Special Feautres:

The Transportation Sector Model has been created to allow the user to change various exogenous and endogenous input levels. The range of policy issues that the transportation model can evaluate are: fuel taxes and subsidies; fuel economy levels by size class; CAFE levels; vehicle pricing policies by size class; demand for vehicle performance within size classes; fleet vehicle sales by technology type; alternative-fuel vehicle sales shares; the Energy Policy Act; Low Emission Vehicle Program; VMT reduction; and greenhouse gas emissions levels.

Modeling Techniques:

The modeling techniques employed in the Transportation Sector Model vary by module: econometrics for passenger travel, aviation, and new vehicle market shares; exogenous engineering and judgement for MPG, aircraft efficiency, and various freight characteristics; and structural for light-duty vehicle and aircraft capital stock estimations.

Computing Environment:

- Hardware Used: IBM RS6000
- Operating System: AIX Version 4.2.1
- Language/Software Used: XL FORTRAN90, Ver 4.0
- Memory Requirement: 9,500 K
- Storage Requirement: 35,000 K
- Estimated Run Time: 15 Seconds
- Special Features: None.

Independent Expert Reviews Conducted:

Independent Expert Review of Transportation Sector Component Design Report, June, 1992, conducted by David L. Greene, Oak Ridge National Laboratory.

Status of Evaluation Efforts by Sponsor:

None.

DOE Input Sources:

- State Energy Data System (SEDS), 1991, May 1993.
- Residential Transportation Energy Consumption Survey (RTECS), 1991, December 1993
- U.S. Department of Energy, Office of Policy, Planning and Analysis, "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector", Technical Report Ten: Alternative Fuel Requirements, 1992.

Non-DOE Input Sources:

- National Energy Accounts
- Federal Highway Administration, Highway Statistics, 1996
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Appendix D. Data Quality and Estimation

LIST OF TABLES

Appendix D. Data Quality and Estimation

This appendix presents results of the statistical tests conducted for those componenents of the transportation model which rely on econometric estimations. These components include: The Fuel Economy Model, the Alternative Fuel Vehicle Model, the Vehicle-Miles Traveled Model, and the Air Travel Demand Model. To date, no data quality studies have been conducted in order to validate the transportation model's input data.

Fuel Economy Model

The methodology employed to assess the influence of macroeconomic and time-dependent variables on the mix of size classes and performance was log-linear regression analysis using historical data on car and light truck sales over the 1979-1990 period. Greater detail is provided in Attachment 1 of Appendix F.

The following equations were used to estimate the CLASS$SHR, class market shares of new vehicle purchases:

<u>All Vehicle Classes Except Luxury Cars:</u>[1]

$$\begin{aligned} DIFF\$LN = {} & A * \ln\left(\frac{YEAR}{CLYEAR}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{CLYEAR}}\right) \\ & + C * \ln\left(\frac{INCOME_{YEAR} - \$13{,}000}{INCOME_{CLYEAR} - \$13{,}000}\right) \\ & + D * \ln\left(\frac{PRICE_{YEAR}}{PRICE_{CLYEAR}}\right) \end{aligned} \qquad \textbf{(D-1)}$$

where:

DIFF$LN = The market share increment from the base year CLYEAR
FUELCOST = The price of gasoline
INCOME = Per capita disposable income
PRICE = Vehicle price

[1]Note: Market shares for Mini and Sub-Compact cars are solved jointly. The resulting combined market share is allocated between the two classes based on the original 1990 allocation. Special treatment of these two classes was made necessary by the small sample size in the analysis data sets.

<u>Luxury Cars:</u>

$$DIFF\$LN = A * \ln\left(\frac{YEAR}{CLYEAR}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{CLYEAR}}\right) + C * \ln\left(\frac{INCOME_{YEAR}}{INCOME_{CLYEAR}}\right) + D * \ln\left(\frac{PRICE_{YEAR}}{PRICE_{CLYEAR}}\right) \tag{D-2}$$

The values of the coefficients with their associated T-statistics are provided below in Table D-1.

<u>Class Market Shares:</u>

$$CLASS\$SHARE_{i,YEAR} = \frac{e^{(RATIO\$LN)}}{1 + e^{(RATIO\$LN)}} \tag{D-3}$$

Where:

$$RATIO\$LN = DIFF\$LN + \ln\left(\frac{CLASS\$SHARE_{CLYEAR}}{1 - CLASS\$SHARE_{CLYEAR}}\right) \tag{D-4}$$

Table D-1A. Regression Results From The Market Share Model

Group	F Val	R^2	Intercept	YEAR	FUELCOST	INCOME
Mini and Subcompact	14.359	0.891	-5.428	0.056 (1.761)	1.33 (1.828)	-0.169 (-1.524)
Sports	11.193	0.808	-2.475	-0.049 (-1.903)	0.26 (.466)	.0068 (.059)
Compact	5.533	0.76	-5.021	0.111 (2.117)	1.332 (1.35)	0.107 (.52)
Intermediate	3.084	0.536	-1.01	-0.051 (-1.742)	-0.213 (-.335)	-0.0017 (-.013)
Large	16.880	0.864	-3.312	-0.119 (-4.754)	0.042 (.077)	0.231 (2.018)
Luxury	18.458	0.939	-3.1	0.126 (2.336)	1.166 (2.704)	0.169 (1.441)
Mini Truck	1.378	0.341	2.268	-0.018 (-.168)	-3.648 (-1.6)	-0.968 (-2.027)
Compact Pickup	19.183	0.916	-8.749	-0.042 (-1.238)	-0.811 (-1.48)	0.174 (1.247)
Compact Van	804.167	0.998	-9.3	0.01 (.352)	0.832 (1.727)	0.307 (3.045)
Compact Utility	274.104	0.994	-7.36	-0.042 (-1.447)	-0.2 (-.396)	0.366 (2.933)
Standard Size Trucks	1.582	0.475	-2.779	-0.056 (-1.523)	0.252 (.307)	0.144 (.846)

Table D-1B. Vehicle Price Elasticities added to LDV Size Class Equations

CAR	DOMESTIC	IMPORT
Mini	-4.09	-3.03
Subcompact	-3.29	-3.68
Sports	-4.09	-3.03
Compact	-3.42	-4.03
Intermediate	-4.18	-5.15
Large	-4.71	-4.71
Luxury	-1.91	-2.74

LIGHT TRUCK		
Mini Truck	-3.53	-2.69
Compact Pickup	-3.53	-2.69
Compact Van	-4.36	-4.66
Compact Utility	-1.07	-1.53
Standard Pickup	-3.53	-2.69
Standard Van	-4.36	-4.66
Standard Utility	-1.07	-1.53

Source: Goldberg, Pinelopi Koujianou, "Product Differentiation and Oligopoly In International Markets: The Case of the U.S. Automobile Industry," Econometrica, vol. 63, No.4, pgs. 891-951, July 1995.

These vehicle price elasticities were added to the size class sales share equations contained in the Fuel Economy Module.

Alternative Fuel Vehicle Model

The AFV model uses a multinomial nested logit approach to estimate market shares of sixteen vehicle technologies. Model coefficients were developed from a survey sponsored by the U.S. Department of Energy, Office of Transportation Technologies, using a national stated preference survey. Market shares are based on the exponentiated value of the consumer utility function, represented as follows:

$$\begin{aligned} VC1_{AFVTECH,REG} = EXP\,[\, & X_1\, PSPR1_{AFVTECH} + X_2\, FLCOST1_{AFVTECH,REG} \\ & + X_3\, VRNG1_{AFVTECH} + X_4\, TPSD1_{AFVTECH} + X_5\, ACCL1_{AFVTECH} \\ & + X_6\, DR2501_{AFVTECH} + X_7\, DR2001_{AFVTECH,REG} \\ & + X_8\, MFUEL1_{AFVTECH,REG} + X_9\, HFUEL1_{AFVTECH} + X_{10}\, MAINT1_{AFVTECH} \\ & + X_{11}\, LUGG1_{AFVTECH} + X_{14}\, RGT2501_{AFVTECH} \\ & + \beta_{FA}\, FAVL1_{AFVTECH,REG} + \beta_{FA2}\, FAVL1^{2}_{AFVTECH,REG} + CALIB\,] \end{aligned} \tag{D-5}$$

where:

VC1 = Consumer utility associated with valuation of VC1 equation
PSPR1 = Price of each AFV technology in nominal $
FLCOST1 = Fuel operating costs for each AFV technology in nominal $
VRNG1 = Vehicle range of the considered technology
TPSD1 = Top speed in mph
ACCL1 = Acceleration from 0-30 mph in seconds
DR2501 =Dummy variable for gasoline capable vehice with range >250 miles
DR2001 =Dummy variable for gasoline capable vehicle with range >250 miles
MFUEL1 = Dummy variable for multi-fuel vehicles
HFUEL1 = Dummy variable for home refueling for EV's
MAINT1 = Maintenance and battery replacement costs in nominal $
LUGG1 = Luggage space indexed to gasoline in in^3
RGT2501 = Gasoline capable vehicle with range in excess of 250 miles
FAVL1= Fuel availability indexed to gasoline fuel availabity by census division
FAVL1^2= Fuel availability squared term
CALIB = Calibration term used to match historical AFV sales in 1998

It is important to note that each coefficient varies by size class across both cars and light trucks. For more detail see Volume II appendix F.

Model coefficients and relevant T-statistics are provided on the following page. An extensive description of the data base development process is provided as an attachment in Appendix F.

Table D-2. AFV Estimated Equations and Statistical Properties of the National Alternative-Fuel Vehicle Survey (Version 33 from 8/7/98)

Variable	Size Class	Coefficient	Standard Error	Z statistic= Coefficient/Standard Error
Purchase price (nominal $) PSPR				
	nev	-7.07E-05	8.27E-05	-.855
	scar+ccar	-6.79E-05	1.32E-05	-5.145
	mcar+lcar	-4.11E-05	4.82E-06	-8.543
	cpickup+spickup+ stdvan	-7.31E-05	1.17E-05	-6.263
	minivan	-1.13E-04	1.74E-05	-6.475

	suv+ssuv	-3.52E-05	9.55E-06	-3.689
Fuel cost (nominal $/mi) FLCOST				
	nev	-2.12E-01	5.70E-01	-.372
	scar+ccar	-1.12E-01	3.99E-02	-2.805
	mcar+lcar	-8.65E-02	2.77E-02	-3.122
	cpickup+spickup+ stdvan	-5.37E-02	2.11E-02	-2.541
	minivan	4.22E-02	4.43E-02	.952
	suv+ssuv	-1.08E-01	2.51E-02	-4.295
Maximum range: dedicated AFV's (electric & gaseous) (miles) VRNG				
	nev	4.92E-03	3.65E-03	1.348
	scar+ccar	4.74E-03	2.23E-03	2.127
	mcar+lcar	3.05E-03	1.35E-03	2.252
	cpickup+spickup+ stdvan	-2.25E-05	1.63E-03	-0.014
	minivan	5.22E-03	2.63E-03	1.985
	suv+ssuv	3.20E-03	1.47E-03	2.18
Gasoline capable range in excess of 250 miles (miles) RGT250				

	gasoline vehicle	-3.39E-03	1.39E-03	-2.436
	alcohol vehicle	-7.48E-04	1.56E-03	-0.478
	dual fuel gaseous	-2.47E-03	3.91E-03	-0.63
	hybrid EV	-4.05E-03	4.36E-03	-0.929
Dummy variable for gasoline capable range >250 miles (0 or 1 value) DR250		1.66E-01	1.38E-01	1.202
Acceleration time 0-30 mpg (secs) ACCL		-6.20E-02	2.40E-02	-2.59
Top Speed (mph) TPSD		3.04E-03	1.80E-03	1.694
Dummy variable for gasoline capable (0 or 1 value) DR200		1.23E+00	2.98E-01	4.121
Dummy variable for multi-fuel capability (0 or 1 value) MFUEL		-5.80E-01	1.41E-01	-4.122
Dummy variable for home re-fueling (EV's) (0 or 1 value) HFUEL		1.86E-01	1.36E-01	1.363

Maintenance & battery replacement costs (nominal $/yr) MAINT		-4.55E-04	1.75E-04	-2.605
Luggage space indexed to gasoline vehicle (0 to 1 value) LUGG		3.35E-03	1.35E-03	2.477

The original equation estimated also included the following variables to capture the effects of refueling infrastructure advances in the future. These variables although estimated simultaneously with the other variables, were not included in the AFV model because of the excessive feedback effects of lagged variables which are implicit in the formulation. Several of the AFV technology coefficients are also statistically insignificant. The infrastructure variable was named NUM and referred to the number of AFV's on road of a particular type.

Table D-3. Infrastructure Variable Excluded From the AFV Module

Variable	AFV Technology	Coefficient	Standard Error	Z Statistic
Number of AFV's on Road				
	dedicated EV	-2.85E-03	2.27E-03	-1.256
	hybrid EV	-2.29E03	3.32E-03	-0.69
	alcohol fueled vehicle	1.30E-03	5.57E-04	2.334
	dedicated gaseous vehicle	-3.23E-04	7.16E-04	-0.451
	dual fuel gaseous vehicle	1.36E-03	5.52E-04	2.46

Fuel Availability Capped at 10%: dedicated gaseous no home refueling		4.45E-02	2.14E-02	2.076

The fuel availability coefficients from the original NEMS model were used in replace of the fuel availability/infrastructure variables contained in the original National Alternative-Fuel Vehicle Survey.[2]

Table D-4. NEMS AFV Model Replacement Variables for Fuel Availability/ Infrastructure

Fuel Availability (# stations/sq. 20 miles) (indexed to gasoline=1.0)	Variable	Coefficient	Standard Error	Z Statistic
	Fuel Availability	2.96	.52	5.7
	Fuel Availability^2	-1.63	.47	-3.5

Other changes were made to the original variables estimated from the National Alternative-Fuel Vehicle survey estimates. The gasoline dummies for 1) gasoline capable vehicles with range greater than 250 miles, and 2) gasoline capable vehicles were both scaled relative to the gasoline vehicle range within each size class. Therefore, only the gasoline vehicle received the full dummy value of 1.0 times the coefficient. The other gasoline capable vehicles received the fraction of the dummy coefficient corresponding to its fraction of range as a percent of the gasoline vehicle range. Furthermore, at the first stage of the logit equation, in which gasoline vehicles and diesel vehicles are competed against a sales-weighted average AFV vehicle, the diesel vehicle was not given the gasoline capable dummy, but instead used the gasoline capable greater than 250 miles dummy variable.

[2]Bunch, David, M. Bradley, T.F. Golob, R. Kitamura, and G.P. Occhiuzzo, *"Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Study,"* Transportation Research, Vol. 27A, pp. 237-253, 1993.

Conversely, at the first stage of the logit equation, the gasoline vehicle was provided with the gasoline capable dummy variable, but did not use the gasoline capable greater than 250 miles dummy variable. All of these adjustments were used to mitigate the penetration of diesel and gasoline vehicles. A large part of the reason for these changes to the originally estimated coefficients from the National Alternative-Fuel survey equations, result from the inclusion of diesel vehicles, which the survey did not originally include. Several other technologies included in NEMS, such as direct injection turbo diesels, diesel electric hybrids, and fuel cell vehicles, were not contained as a part of the survey. These technologies pose difficulties for the estimated equations because their vehicle attributes are usually outside of the normal range of values associated with AFV's.

Vehicle-Miles Traveled Model

Vehicle-miles traveled is estimated on a per capita basis using a generalized difference equation, estimated using the Cochrane-Orcutt iterative procedure:

$$VMTPC_T = \rho\, VMTPC_{T-1} + 0.899\,(1-\rho) - 0.104\,(CPM_T - \rho\, CPM_{T-1}) + 2.5x10^{-4}\,(YPC_T - \rho\, YPC_{T-1}) + 3.933\,(PrFem_T - \rho\, PrFem_{T-1}) \quad \text{(D-6)}$$

where:

CPM = The cost of driving a mile in $92 chain-weighted dollars
YPC = Disposable personal income per capita, in $92 chain-weighted dollars
PrFem = The ratio of per capita female driving to per capita male driving.

The parameters and relevant T-statistics are provided in Table D-5, below.

Table D-5. Model of VMT per Capita

	$\hat{\rho}$	α	**CPM92**	**YPC92**	**PrFem**	**Adj. R-Sq**
Parameter **T-Statistic**	0.768	0.899	-.104 -4.3	2.5 e-04 3.8	3.933 3.0	0.879

Air Travel Demand Model

This report presents the results of a re-estimation of the four equations comprising the Air Travel Demand Model. This model was originally estimated in 1992, using data from the years following the deregulation of airlines. With the acquisition additional data, and the revision of major macroeconomic variables, the parameters have been recalculated and are presented, along with the supporting data, on the following pages.

Although various alternative specifications were tested with the updated data sets, three of the four original equations provided results with the highest explanatory power.[3] The single equation which has been altered is that representing average travel costs in the "yield" equation: the non-fuel operating cost has been eliminated as an input due to its relatively static nature over the course of time, and its subsequent lack of explanatory significance.

In all of the regressions, the Durbin-Watson statistic indicates that autocorrelation may be present, but efforts to correct for this using a lagged-dependent variable approach have not provided acceptable results. In conclusion, the suggested model specification represents a simple forecasting tool which is sensitive to aircraft fuel prices and measures of economic activity. With a periodic updating of data and the re-estimation of these equations, the level of confidence in this approach should increase.

Table D-6. Regression Results From The Yield Model

$$YIELD = 9.50 + .82\ TPJFTR$$

SE		.62
t		13.62

$$Adj.R^2 = .91 \qquad D-W = 1.16$$

Sources:

(1) **TPJFTR:** U.S. Department of Transportation, Research and Special Programs Administration (RSPA), *Fuel Cost And Consumption Tables*, annual summaries, 1979-1995.

(2) **YIELD:** Quotient of Passenger Revenue and RPM. **Passenger Revenue:** U.S. Department of Transportation, Bureau of Transportation Statistics, Air Carrier Financial Statistics Monthly, December 1995/1994, and prior issues, lines 3, 12.

[3] For a description of the development of this model, see Volume I.

Table D-7. Regression Results From The Business Travel Demand Model

$$RPMBPC = -248.38 + 39.0\, GDPPC92 - 3.86\, YIELD$$

SE		.01	8.65
t		4.76	−0.45

$Adj.R^2 = 0.87$ $\quad D{-}W = 1.64$

Sources:

(1) **RPMBPC:** Quotient of Business RPM and Population.

(2) **GDPPC92:** Gross Domestic Product per Capita, in 1992 dollars. From NEMS Macroeconomic Module.

Table D-8. Regression Results Form The Personal Travel Demand Model

$$RPMPPC = -384.97 + 80.0\, YDPC92 - 21.59\, YIELD$$

SE		.01	8.09
t		6.78	−2.67

$Adj.R^2 = .96$ $\quad D{-}W = 1.54$

Sources:

(1) **RPMPPC:** Quotient of Personal RPM and Population.

(2) **YDPC92:** Disposable Personal Income per Capita, in 1992 dollars. From NEMS Macroeconomic Module.

Table D-9. Regression Results From The Dedicated Air Freight Model

$$RTM = (-13{,}136 + 20.92\, MC\_EXDn92C + 3.19\, MC\_GDP92C) - BELLYFRT$$

SE		2.83	0.53
t		7.39	6.04

$Adj.R^2 = .99$ $\quad D{-}W = 1.20$

Sources:

(1) **RTM:** U.S. Department of Transportation, Bureau of Transportation Statistics, *Air Carrier Traffic Statistics Monthly, December 1995/1994,* and prior issues. Lines 18-

21, 46.

(2) **MC_EXDn92C:** Merchandise trade exports, in 1992 dollars, from NEMS Macroeconomic Module.

(3) **MC_GDP92C:** Gross domestic product, in 1992 dollars, from NEMS Macroeconomic Module.

(4) **BELLYFRT:** Ton-miles of freight transported in the belly of the commercial aircraft.

Appendix E. Attachments to the Transportation Model

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Appendix E. Attachments to the Transportation Model

The attachments contained within this appendix provide additional details about the model development and estimation process which do not easily lend themselves to incorporation in the main body of the model documentation report. The information provided in these attachments is not integral to the understanding of the model's operation, but provides the reader with the opportunity to gain a deeper understanding of some of the model's underlying assumptions. Each attachment is associated with a specific component of the transportation model.

The following attachments are contained in Appendix E:

Attachment 1: Fuel Economy Model (FEM): Provides a discussion of the FEM vehicle demand and performance by size class models.

Attachment 2: Alternative Fuel Vehicle (AFV) Model: Describes data input sources and extrapolation methodologies.

Attachment 3: Light-Duty Vehicle (LDV) Stock Model: Discusses the fuel economy gap estimation methodology.

Attachment 4: Light Duty Vehicle Fleet Model: Presents the data development for business, utility, and government fleet vehicles.

Attachment 5: Light Commercial Truck Model: Describes the stratification methodology and data sources employed in estimating the stock and performance of LCT’s.

Attachment 6: Air Travel Demand Model: Presents the derivation of the demographic index, used to modify estimates of personal travel demand.

Attachment 7: Airborne Emissions Model: Describes the derivation of emissions factors used to associate transportation measures to levels of airborne emissions of several pollutants.

Attachment 8: LDV Stock Model: Explains the methodology used in determining the forecasts for car and light truck sales shares.

Attachment 9: Freight Truck Technology Model: Reviews the freight truck technology choice methodology and the assumptions about the technology characteristics.

Attachment 1: Fuel Economy Model

Demand Models for Vehicle Size Class Mix
and Performance by Size Class

INTRODUCTION

Estimates of the future mix of vehicle classes sold and the performance level by size class requires a detailed econometric demand model of vehicle choice by size class and vehicle performance within size class. There are a few publicly available models that forecast vehicle demand by size class, but those models have proved inaccurate in the past, and do not use a class structure that is compatible with the one used in the FEM. Demand for performance has not been assessed to date in any publicly available study. Both the size mix and performance levels are difficult to estimate because the car purchase decision is complex and consumer choice depends not only on the macroeconomic conditions but also on the attributes of individual products in the marketplace. Some of these attributes are based on the styling of the car, its perceived quality, the manufacturer's image and the status conveyed by owning a specific model, and cannot be easily quantified. Although these variables affect choice of individual models, they can also affect the choice of vehicle sizes or performance levels. For example, many consumers appeared to willing to buy a Japanese car for its quality and reliability even if it's size was smaller than the size actually desired by consumers. There have also been changes in consumer performance that may be linked to demographic variables, e.g., older consumers prefer larger cars.

These factors have made the automotive market notoriously difficult to forecast. The models incorporated in the FEM do <u>not</u> represent an attempt to provide a comprehensive forecast of future shifts in size class mix or performance levels by size class in response to the potentially large range of influencing or causal variables. Rather, the models attempt to capture the response to broad macroeconomic forces or behavioral (time) trends based on the experience of the last 15 years. It is recognized that these models are relatively simplistic, and it is anticipated that future versions of the FEM will incorporate more advanced models.

METHODOLOGY

The methodology employed to assess the influence of macroeconomic and time dependent variables on the mix of size classes and performance was by regression analysis of historical data.

EEA has compiled a very large data base on car and light truck sales over the 1979-1990 period. These data are based on the official CAFE files from EPA, augmented by the addition of vehicle and engine descriptor variables. All of the vehicles were classified by market class according to the scheme utilized in the FEM. Vehicle performance levels were measured by the horsepower to weight ratio (HP/WT) that is well correlated to objective measures such as the 0 to 60 mph acceleration time. Detailed weight data was unavailable for light trucks, and horsepower alone was used as a surrogate for performance. (Fortunately, truck weight within market class did not change significantly in the 12 year period analyzed).

The models for size class mix and performance utilized the same set of independent variables

- Disposable income per capita (in 1990 dollars)
- Price of gasoline (1990 dollars)
- Vehicle price average by class
- Vehicle fuel economy
- Rate of change of gas price over two years
- Cost of driving per mile
- Number of nameplates (models) in a class

The last variable is really a composite of fuel cost/fuel economy and not a new independent variable.

Performance was defined as the average HP/WT ratio by class for cars, and the average HP by class for trucks. Market share was defined as the sales fraction of the class relative to entire car and light truck market. This definition was chosen to incorporate the effects of consumers switching from cars to light trucks.

In general, the models were linear regressions of the logarithm of all variables, so that the co-efficients represented "elasticity" estimates. However, the market share model was modified to utilize the variable (m/1-m) as the independent variable in the regression, for two reasons. First, the elasticity of market share appears to be dependent on how large a share of the market a size class has. This reflects the fact that at very low market shares, buyers of a particular class are reduced to the diehard consumers who are less likely to switch due to macroeconomic forces, and the market is inelastic. Second the log(m/1-m) form converts a 0 to 1 variable to one that spans the -infinity to +infinity range. As a result of this variable change the model cannot be driven to m=1 for any input set, so that no one market class takes over the entire market for any combination of inputs. Such a variable form has been utilized in prior analysis by Wheaton Econometric Forecasting Associates (WEFA).

RESULTS

A stepwise linear regression of performance by market class and of class market share was performed to aid in the selection of independent variables with the greatest statistical significance. In addition, the co-efficients were required to be

- directionally consistent with intuitive expectations
- consistent in absolute magnitude across market classes that are similar

For the market share regressions, the variables that were statistically significant included: model year (time), price of gasoline, disposable income, number of nameplates (in some classes). In particular, number of nameplates was significant in those classes where only one or two makes existed in the early 1980's but new makes were introduced in the mid-to-late 1980's; compact vans are a good example of this phenomenon.

Table E-1 shows the results of the regressions of (m_i/1-m_i) against the variables MDLY (model year), LPGAS (price of gasoline), LYD (per capita disposable income), and LNPLT (number of nameplates). The following conclusions are appropriate:

- Subcompact and minicompact market share benefits from a time trend towards smaller cars. Market share increases with increasing gasoline prices (1.33 co-efficient) but decreases with increasing income.
- Sports cars market share appears to be declining with time but is insensitive to price of gasoline or income.
- Compact car market share increase with time and increasing price of gasoline, but is insensitive to income trends.

Table E-1. Regression Results From LDV Market Share Model

Group	F Val	R^2	Intercept	MDLY	LPGAS	LYD	LNPLT
Mini and Subcompact	14.359	0.891	-5.428	0.056 (1.761)	1.33 (1.828)	-0.169 (-1.524)	1.136 (2.288)
Sports	11.193	0.808	-2.475	-0.049 (-1.903)	0.26 (.466)	.0068 (.059)	
Compact	5.533	0.76	-5.021	0.111 (2.117)	1.332 (1.35)	0.107 (.52)	0.383 (.825)
Intermediate	3.084	0.536	-1.01	-0.051 (-1.742)	-0.213 (-.335)	-0.0017 (-.013)	
Large	16.880	0.864	-3.312	-0.119 (-4.754)	0.042 (.077)	0.231 (2.018)	
Luxury	18.458	0.939	-3.1	0.126 (2.336)	1.166 (2.704)	0.169 (1.441)	-0.435 (-.699)
Mini Truck	1.378	0.341	2.268	-0.018 (-.168)	-3.648 (-1.6)	-0.968 (-2.027)	
Compact Pickup	19.183	0.916	-8.749	-0.042 (-1.238)	-0.811 (-1.48)	0.174 (1.247)	1.91 (5.122)
Compact Van	804.167	0.998	-9.3	0.01 (.352)	0.832 (1.727)	0.307 (3.045)	1.466 (16.421)
Compact Utility	274.104	0.994	-7.36	-0.042 (-1.447)	-0.2 (-.396)	0.366 (2.933)	0.763 (8.474)
Standard Size Trucks	1.582	0.475	-2.779	-0.056 (-1.523)	0.252 (.307)	0.144 (.846)	

- Intermediate car market share is decreasing with time but is largely insensitive to either the price of gasoline or income.
- Large car market share decreases with time, but increases with income.
- Luxury car market share increases with time, income and the price of gasoline.
- Minitruck market share is very sensitive to the price of gasoline, and decreases with increasing gasoline prices and income.
- Compact trucks and utilities market share are negatively influenced by time trends and price of gas, but positively by income.
- Compact vans have a unique trend relative to all trucks in showing increasing market share with increasing gasoline prices. It is also positively influenced by increasing income.
- Full size trucks (pickup, van and utility) show relatively stable market shares, with a modestly declining time trend. Only utility vehicles' market share appear to be sensitive to income, while market shares of all full size trucks are insensitive to the price of gasoline.

Some of these trends initially appear to be counterintuitive, but one must consider the impact of a particular variable on sales of the class as well as the total fleet sales. For example, while sales of luxury cars decreases with increasing gasoline prices, the market share increases since sales of all other cars decline by a greater amount for the same change in the price of gasoline. Sales of minitrucks and compact pickup and utility vehicles, most of which are used for personal transportation or recreation, are also more strongly affected by increasing price of gasoline, and their market share drops. On the other hand, standard size vehicles are used more commonly in the light commercial sector or for hauling rather than personal transportation and their market shares are relatively stable in response to gasoline prices.

It should be noted that the co-efficients in Table E-1 are not elasticities as the dependent variable is $m_i/1-m_i$, not m_i alone. In general, the values of m_i range from 0.05 to 0.20. The correct "elasticity" co-efficient is the actual co-efficient times $1-m_i/2$, so that multiplying the co-efficients in Table E-1 by 0.4 ~ 0.475 will provide an estimate of elasticity.

The performance model utilized a similar procedure, but the dependent variable was average HP/WT (or HP for trucks) by class. The most significant variables were found to be LFC (fuel consumption), personal income (LYD) and price of gas (LPGAS) in most cases. In some cases, cost per mile (LCPM) provided a better regression when substituted for LFC and LPGAS. The results of the regression are shown in Table E-2. In general, the regressions yield the elasticities presented in Table E-3.

The results indicate that virtually all classes respond similarly to the cost of driving, although for small cars (mini-, sub-, and compact cars) an equivalent result was obtained for fuel economy rather than cost per mile. Performance demand is more sensitive to disposable income, with the large trucks showing very high sensitivity. This particular finding is suspect and may be due to the fact that significant engine improvements in the late 1980's (which increased rated HP) occurred in the same time frame when incomes were rising.

Table E-2. Regression Results From LDV Performance Model

Group	F Val	R^2	Intercept	LFC	LYD	LPGAS
Mini and Subcompact	14.819	0.848	13.893	-0.238 (1.706)	1.012 (-2.270)	0.11 (-.811)
Sports	7.675	0.742	-1.104	-0.311 (1.299)	-0.533 (.666)	-0.364 (1.616)
Compact	11.613	0.813	20.709	-0.252 (3.094)	1.721 (-3.308)	0.403 (-2.679)
Intermediate	57.101	0.956	14.252	-0.099 (.845)	1.114 (-3.296)	-0.0051 (.050)
Large	72.509	0.964	10.429	-0.168 (1.380)	0.704 (-1.902)	-0.171 (1.535)
Luxury	151.145	0.983	11.085	-0.124 (1.859)	0.79 (-2.704)	-0.248 (2.912)
Mini Truck	0.219	0.076	0.88	0.378 (.550)	0.483 (.230)	0.035 (.056)
Compact Pickup	35.043	0.929	-9.264	-0.119 (-.646)	1.409 (3.045)	0.03 (.228)
Compact Van	57.789	0.956	-33.712	-0.853 (-2.375)	3.722 (2.960)	-0.0044 (-.012)
Compact Utility	21.804	0.891	-10.507	0.586 (2.824)	1.785 (2.149)	-0.063 (-.264)
Standard Pickup	16.854	0.863	-17.358	0.276 (1.315)	2.41 (3.182)	0.271 (1.257)
Standard Van	37.117	0.933	-14.171	0.142 (1.061)	2.038 (4.393)	0.195 (1.72)
Standard Utility	21.177	0.888	-19.425	0.331 (2.144)	2.54 (3.398)	0.253 (1.176)

Table E-3: LDV Performance Model Elasticities

	LFC	LYD	LPGAS	LCPM
Small Cars	-0.23 ~ -0.30	+1 to +1.7	N.S.	--
Large Cars	-0.10 ~ -0.17	0.7 to 1.0	Variable	-0.1 to -0.20
Small Trucks	N.S.	+1.4 to +1.7	N.S.	-0.24 to -0.33
Standard Trucks	N.S.	-2.0 to 2.5	N.S.	-0.23 to -0.35

N.S. - Not Specified

VALUE OF PERFORMANCE AND FUEL ECONOMY ADJUSTMENT

The value of performance is defined as the dollar amount that consumers are willing to pay for horsepower. This value was estimated from the actual list price for the vehicles in the 1988-1990 period and was based on the engine option prices. This method assumes that the manufacturers are pricing horsepower at levels that consumers are willing to pay. Most domestic models offer an optional engine with higher HP, while several import models offer optional turbocharged engines or 4-valve engine versions. In each case the cost of the engine option alone was identified from manufacturer price lists for 1989/1990 models (very often, the engine option is available with other features such as performance tires, aerodynamic devices etc. so that the vehicle price is higher than the cost of the engine option). Based on the prices of engine options, the following averages are applicable for all cars except sports and luxury cars:

Table E-4. LDV Performance and Price Options

Engine Option	HP Gain (%)	Price	Price/% HP
4-Valve vs. 2-Valve	30 to 35	$400 to 500	13.30 to 16.66
V-6 vs. I-4	25 to 30	$300 to 400	12 to 16
V-8 vs. V-6	30 to 35	$400 to 500	13.30 to 16.66
Turbo vs. Nat Aspirated	45 to 60	$650 to 850	14.44 to 18.88

Based on these data, an approximate average value of performance is $15 per percent increase in HP. Most sports and several luxury cars charge prices that are 15 to 25 percent higher than the values quoted above (although some very high priced luxury cars such as Mercedes, Porsche, and BMW charge more than twice the values quoted above). Accordingly, the value of performance for these classes has been set to $18 per percent increase in HP.

Increasing performance also decreases fuel economy and this relationship is derived from a regression analysis of fuel economy data that provides the sensitivity of fuel economy to factors that increase performance. In general, performance can be increased by four methods:

- by increasing the axle ratio
- by installing a larger engine with the same number of cylinders
- by installing a larger engine with more cylinders
- by utilizing 4-valve heads or turbocharging

The first method is suitable only for small changes in performance (less than 10 percent). The second method is useful for changes in the range of 10 to 25 percent. The use of engines with more cylinders can result in HP gains of 30 to 60 percent (4 cylinder to 6 cylinder, or 6 cylinder to 8 cylinder). 4-valve engines generally provide HP gains of 20 to 25 percent relative to a 2-valve engine of equal displacement, while turbocharging can provide an HP increase of 40 to 45 percent relative to a naturally aspirated engine of equal displacement. These technologies can be combined with displacement increases or decreases to achieve any desired result.

Based on engineering and regression analysis (see Appendix G, Supplement 1), the fuel economy sensitivity for axles ratio changes is -0.22 (i.e., a 10 percent axle ratio increase decreases fuel economy by 2.2 percent). The fuel economy sensitivity for displacement changes without changing the number of cylinders is -0.35 (i.e. a 25 percent change in displacement decreases fuel economy by nine percent, including the effect of increased engine weight). Substituting a V-6 for a 4-cylinder or a V-8 for a V-8 significantly increases the vehicle weight, and a fifty percent HP increase decreases fuel economy by about 25 percent.

A non-linear equation that captures these effects is given by

$$\Delta FE = -0.22\,\Delta HP - 0.56\,\Delta HP^2 \;; \qquad \Delta HP > 0$$

$$= -0.22\,\Delta HP + 0.56\,\Delta HP^2 \;; \qquad \Delta HP < 0$$

where both ΔHP and ΔFE are expressed as *percent changes*. The equation is valid for ΔHP values between 0 and 60 percent.

TECHNOLOGY IMPROVEMENTS FOR AUTOMOBILES

The characteristics of the automotive technologies considered in the LDV module have been developed by Energy and Environmental Analysis, Inc. of Arlington Virginia, and are tabulated on the following pages in Tables F-6 to F-9.[1] Much of this research has been derived from an earlier study of technological change and its potential application to fuel economy improvements.[2] In this study, numerous automotive technologies have been evaluated in regard to both their estimated impacts on vehicle performance and their cost-effectiveness from a producer's standpoint. Individual technologies or groups of technologies have been assigned to one of three "certainty levels", defined below, which indicates the likelihood of their incorporation in the near-term.

The Standard Technology Matrices for cars and light trucks (Tables F-6 and F-7) represent a relatively conservative estimation of technology cost, availability, and impact over the course of the forecast. The corresponding High Technology Matrices (Tables F-8 and F-9) reflect a more optimistic assessment of the potentials of selected technologies. In order to permit a ready comparison of technology characteristics, those elements in the High Technology Matrices which differ from their Standard Technology counterparts are shaded.

Table E-5: Certainty Levels of Near-Term Technologies for Improving Fuel Economy[3]

Level	Technology Characteristics
1	Technologies currently in production in at least one mass market vehicle worldwide and which have no technical risk in the sense that they are fully demonstrated and are available to all manufacturers through either direct production or licensing. Level 1 improvements are therefore available for production use within one product cycle.
2	Technologies ready for commercialization and for which there are no engineering constraints (such as emissions control considerations) which would inhibit their use in production vehicles. Technologies assessed at Level 2 are considered to have low technical risk in the sense that some "debugging" effort may be required because of a lack of on-road experience
3	Technologies in advanced stages of development but which may face some technical constraints before they can be used in production vehicles. Because Level 3 technologies bear some uncertainty as to when they will be fully available for use in production, it is not possible to presently establish with certainty that they are available for incorporation into new vehicles over the course of a complete product cycle.

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[1] *NEMS Fuel Economy Model: LDV High Technology Update,* Decision Analysis Corporation of Virginia, DE-AC01-92EI21946, Task 95124, Subtask 9-2, 6/17/96.

[2] DeCicco, J., and Ross, M., *An Updated Assessment of the Near-Term Potential for Improving Automotive Fuel Economy,* American Council for an Energy-Efficient Economy, Washington DC, 11/93.

[3] *Ibid.* p. 12.

Table E-6: Standard Technology Matrix For Cars

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.060	160	0.00	0	-0.08	1980	0
Unit Body	0.040	80	0.00	0	-0.05	1980	0
Material Substitution II	0.033	0	0.60	0	-0.05	1987	0
Material Substitution III	0.066	0	0.80	0	-0.10	1997	0
Material Substitution IV	0.099	0	1.00	0	-0.15	2007	0
Material Substitution V	0.132	0	1.50	0	-0.20	2017	0
Drag Reduction II	0.023	32	0.00	0	0.00	1985	0
Drag Reduction III	0.046	64	0.00	0	0.05	1991	0
Drag Reduction IV	0.069	112	0.00	0	0.01	2004	0
Drag Reduction V	0.092	176	0.00	0	0.02	2014	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1995	0.07
CVT	0.100	250	0.00	20	0.00	1995	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1991	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1988	0
Electronic Transmission II	0.015	40	0.00	5	0.00	1998	0
Roller Cam	0.020	16	0.00	0	0.00	1987	0
OHC 4	0.030	100	0.00	0	0.00	1980	0.2
OHC 6	0.030	140	0.00	0	0.00	1980	0.2
OHC 8	0.030	170	0.00	0	0.00	1980	0.2
4C/4V	0.080	240	0.00	30	0.00	1988	0.45
6C/4V	0.080	320	0.00	45	0.00	1991	0.45
8C/4V	0.080	400	0.00	60	0.00	1991	0.45
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1988	-0.1
4C/5V	0.100	300	0.00	45	0.00	1998	0.55
Turbo	0.050	800	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1987	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	1996	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2006	0
Engine Friction Reduction IV	0.065	140	0.00	0	0.00	2016	0
VVT I	0.080	140	0.00	40	0.00	1998	0.1
VVT II	0.100	180	0.00	40	0.00	2008	0.15
Lean Burn	0.100	150	0.00	0	0.00	2012	0
Two Stroke	0.150	150	0.00	-150	0.00	2004	0
TBI	0.020	40	0.00	0	0.00	1982	0.05
MPI	0.035	80	0.00	0	0.00	1987	0.1
Air Pump	0.010	0	0.00	-10	0.00	1982	0
DFS	0.015	15	0.00	0	0.00	1987	0.1
Oil 5W-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	16	0.00	0	0.00	1992	0
Tires II	0.020	32	0.00	0	0.00	2002	0
Tires III	0.030	48	0.00	0	0.00	2012	0
Tires IV	0.040	64	0.00	0	0.00	2018	0
ACC I	0.005	15	0.00	0	0.00	1992	0
ACC II	0.010	30	0.00	0	0.00	1997	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1987	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1994	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2003	0
ABS	-0.005	300	0.00	10	0.00	1987	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Idle Off	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Optimized Manual Transmission	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Variable Displacement	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Electric Hybrid	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table E-7: Standard Technology Matrix For Trucks

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.020	160	0.00	0	-0.08	1985	0
Unit Body	0.060	80	0.00	0	-0.05	1995	0
Material Substitution II	0.033	0	0.60	0	-0.05	1996	0
Material Substitution III	0.066	0	0.80	0	-0.10	2006	0
Material Substitution IV	0.099	0	1.00	0	-0.15	2016	0
Material Substitution V	0.132	0	1.50	0	-0.20	2026	0
Drag Reduction II	0.023	32	0.00	0	0.00	1990	0
Drag Reduction III	0.046	64	0.00	0	0.05	1997	0
Drag Reduction IV	0.069	112	0.00	0	0.01	2007	0
Drag Reduction V	0.092	176	0.00	0	0.02	2017	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1997	0.07
CVT	0.100	250	0.00	20	0.00	2005	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1997	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1991	0
Electronic Transmission II	0.015	40	0.00	5	0.00	2006	0
Roller Cam	0.020	16	0.00	0	0.00	1986	0
OHC 4	0.030	100	0.00	0	0.00	1980	0.15
OHC 6	0.030	140	0.00	0	0.00	1985	0.15
OHC 8	0.030	170	0.00	0	0.00	1995	0.15
4C/4V	0.060	240	0.00	30	0.00	1990	0.30
6C/4V	0.060	320	0.00	45	0.00	1990	0.30
8C/4V	0.060	400	0.00	60	0.00	2002	0.30
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1990	-0.1
4C/5V	0.080	300	0.00	45	0.00	1997	0.55
Turbo	0.050	800	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1991	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	2002	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2012	0
Engine Friction Reduction IV	0.065	140	0.00	0	0.00	2022	0
VVT I	0.080	140	0.00	40	0.00	2006	0.1
VVT II	0.100	180	0.00	40	0.00	2016	0.15
Lean Burn	0.100	150	0.00	0	0.00	2018	0
Two Stroke	0.150	150	0.00	-150	0.00	2008	0
TBI	0.020	40	0.00	0	0.00	1985	0.05
MPI	0.035	80	0.00	0	0.00	1985	0.1
Air Pump	0.010	0	0.00	-10	0.00	1985	0
DFS	0.015	15	0.00	0	0.00	1985	0.1
Oil %w-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	16	0.00	0	0.00	1992	0
Tires II	0.020	32	0.00	0	0.00	2002	0
Tires III	0.030	48	0.00	0	0.00	2012	0
Tires IV	0.040	64	0.00	0	0.00	2018	0
ACC I	0.005	15	0.00	0	0.00	1997	0
ACC II	0.010	30	0.00	0	0.00	2007	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1992	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1996	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2004	0
ABS	-0.005	300	0.00	10	0.00	1990	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Idle Off	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Optimized Manual Transmission	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Variable Displacement	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Electric Hybrid	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table E-8: High Technology Matrix For Cars

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.060	160	0.00	0	-0.08	1980	0
Unit Body	0.040	80	0.00	0	-0.05	1980	0
Material Substitution II	0.033	0	***0.30***	0	-0.05	1987	0
Material Substitution III	0.066	0	***0.40***	0	-0.10	1997	0
Material Substitution IV	0.099	0	***0.50***	0	-0.15	***2003***	0
Material Substitution V	0.132	0	***0.75***	0	-0.20	***2007***	0
Drag Reduction II	0.023	32	0.00	0	0.00	1985	0
Drag Reduction III	0.046	64	0.00	0	0.05	1991	0
Drag Reduction IV	0.069	112	0.00	0	0.01	***1997***	0
Drag Reduction V	0.092	176	0.00	0	0.02	***2003***	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1995	0.07
CVT	0.100	250	0.00	20	0.00	1995	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1991	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1988	0
Electronic Transmission II	***0.090***	***60***	0.00	5	0.00	1998	0
Roller Cam	0.020	16	0.00	0	0.00	1987	0
OHC 4	0.030	***45***	0.00	0	0.00	1980	0.2
OHC 6	0.030	***55***	0.00	0	0.00	1980	0.2
OHC 8	0.030	***65***	0.00	0	0.00	1980	0.2
4C/4V	0.080	***125***	0.00	30	0.00	1988	0.45
6C/4V	0.080	***165***	0.00	45	0.00	1991	0.45
8C/4V	0.080	***205***	0.00	60	0.00	1991	0.45
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1988	-0.1
4C/5V	0.100	300	0.00	45	0.00	1998	0.55
Turbo	***0.080***	***300***	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1987	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	1996	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2006	0
Engine Friction Reduction IV	0.065	***120***	0.00	0	0.00	2016	0
VVT I	0.080	***100***	0.00	40	0.00	1998	0.1
VVT II	0.100	***130***	0.00	40	0.00	2008	0.15
Lean Burn	***0.120***	***75***	0.00	0	0.00	2012	0
Two Stroke	0.150	***0***	0.00	-150	0.00	2004	0
TBI	0.020	40	0.00	0	0.00	1982	0.05
MPI	0.035	80	0.00	0	0.00	1987	0.1
Air Pump	0.010	0	0.00	-10	0.00	1982	0
DFS	0.015	15	0.00	0	0.00	1987	0.1
Oil %w-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	***5***	0.00	0	0.00	1992	0
Tires II	***0.033***	***10***	0.00	0	0.00	2002	0
Tires III	***0.048***	***15***	0.00	0	0.00	2012	0
Tires IV	***0.053***	***20***	0.00	0	0.00	2018	0
ACC I	***0.010***	***5***	0.00	0	0.00	1992	0
ACC II	***0.017***	***13***	0.00	0	0.00	1997	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1987	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1994	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2003	0
ABS	-0.005	300	0.00	10	0.00	1987	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	***0.010***	***0***	***0.00***	***0***	***0.00***	***1995***	***0.02***
Idle Off	***0.110***	***260***	***0.00***	***0***	***0.00***	***1997***	***0***
Optimized Manual Transmission	***0.120***	***60***	***0.00***	***0***	***0.00***	***1997***	***0***
Variable Displacement	***0.030***	***65***	***0.00***	***0***	***0.00***	***1999***	***0***
Electric Hybrid	***0.660***	***1785***	***0.00***	***0***	***0.00***	***2001***	***0***

Table E-9: High Technology Matrix For Trucks

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.020	160	0.00	0	-0.08	1985	0
Unit Body	0.060	80	0.00	0	-0.05	1995	0
Material Substitution II	0.033	0	*0.30*	0	-0.05	*1987*	0
Material Substitution III	0.066	0	*0.40*	0	-0.10	*1997*	0
Material Substitution IV	0.099	0	*0.50*	0	-0.15	*2003*	0
Material Substitution V	0.132	0	*0.75*	0	-0.20	*2007*	0
Drag Reduction II	0.023	32	0.00	0	0.00	*1985*	0
Drag Reduction III	0.046	64	0.00	0	0.05	*1991*	0
Drag Reduction IV	0.069	112	0.00	0	0.01	*1997*	0
Drag Reduction V	0.092	176	0.00	0	0.02	*2003*	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	*1995*	0.07
CVT	0.100	250	0.00	20	0.00	*1995*	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	*1991*	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	*1988*	0
Electronic Transmission II	*0.090*	*60*	0.00	5	0.00	*1998*	0
Roller Cam	0.020	16	0.00	0	0.00	*1987*	0
OHC 4	0.030	*45*	0.00	0	0.00	1980	*0.2*
OHC 6	0.030	*55*	0.00	0	0.00	*1980*	*0.2*
OHC 8	0.030	*65*	0.00	0	0.00	*1980*	*0.2*
4C/4V	*0.080*	*125*	0.00	30	0.00	*1988*	*0.45*
6C/4V	*0.080*	*165*	0.00	45	0.00	*1991*	*0.45*
8C/4V	*0.080*	*205*	0.00	60	0.00	*1991*	*0.45*
Cylinder Reduction	0.030	-100	0.00	-150	0.00	*1988*	-0.1
4C/5V	*0.100*	300	0.00	45	0.00	*1998*	0.55
Turbo	*0.080*	*300*	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	*1987*	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	*1996*	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	*2006*	0
Engine Friction Reduction IV	0.065	*120*	0.00	0	0.00	*2016*	0
VVT I	0.080	*100*	0.00	40	0.00	*1998*	0.1
VVT II	*0.120*	*130*	0.00	40	0.00	*2008*	0.15
Lean Burn	0.100	*75*	0.00	0	0.00	*2012*	0
Two Stroke	0.150	*0*	0.00	-150	0.00	*2004*	0
TBI	0.020	40	0.00	0	0.00	*1982*	0.05
MPI	0.035	80	0.00	0	0.00	*1987*	0.1
Air Pump	0.010	0	0.00	-10	0.00	*1982*	0
DFS	0.015	15	0.00	0	0.00	*1987*	0.1
Oil 5W-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	*5*	0.00	0	0.00	1992	0
Tires II	*0.033*	*10*	0.00	0	0.00	2002	0
Tires III	*0.048*	*15*	0.00	0	0.00	2012	0
Tires IV	*0.053*	*20*	0.00	0	0.00	2018	0
ACC I	*0.040*	*5*	0.00	0	0.00	*1992*	0
ACC II	*0.017*	*13*	0.00	0	0.00	*1997*	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	*1987*	0
Emissions Tier I	-0.010	150	0.00	10	0.00	*1994*	0
Emissions Tier II	-0.010	300	0.00	20	0.00	*2003*	0
ABS	-0.005	300	0.00	10	0.00	*1987*	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	*0.010*	*0*	*0.00*	*0*	*0.00*	*1995*	*0.02*
Idle Off	*0.110*	*260*	*0.00*	*0*	*0.00*	*1997*	*0*
Optimized Manual Transmission	*0.120*	*60*	*0.00*	*0*	*0.00*	*1997*	*0*
Variable Displacement	*0.030*	*65*	*0.00*	*0*	*0.00*	*1999*	*0*
Electric Hybrid	*0.660*	*1785*	*0.00*	*0*	*0.00*	*2001*	*0*

CHARACTERISTICS OF ALTERNATIVE FUEL VEHICLES

This section provides a documentation of the updated Fuel Economy Model that also forecasts attributes of Alternative Fuel Vehicles (AFVs) for incorporation into the NEMS transportation model. The NEMS model requires a forecast of vehicle attributes consistent with those provided for conventional gasoline powered vehicles. The existing AFV module considers only three size classes, and requires five attributes by size class, which includes vehicle price and fuel efficiency as well as range, fuel availability and an estimate of emissions relative to gasoline. In general, fuel availability is specified exogenously, while the Fuel Economy Model (FEM) is expected to supply other attributes. The updated FEM provides attributes for AFVs in up to 12 market classes and five fuel types.

Other than gasoline and diesel powered vehicles, the model considers a variety of alternative fuel vehicles that are of both the dedicated and bi-fuel (alternative fuel/gasoline) type. The fuels considered include methanol, ethanol, electricity, compressed natural gas and liquified petroleum gas for a matrix of 10 alternative fuel vehicle types. The existing AFV module contains two other AFV types that are engine technology based classifications (assuming that the 10 described above use piston i.c. engine based technology). The two others are turbine powered using gasoline or CNG, and fuel cell powered using methanol or pure hydrogen, for an additional four AFV classes.

Available data for the manufacturers suggest that turbine powered vehicles are most unlikely to be produced as they have significantly higher costs and lower fuel economy than i.c. engines of equal power. Fuel cell powered vehicles using either methanol or pure hydrogen are unlikely to see commercial production before 2010. Attributes of all other vehicle types are summarized in this report, and a preliminary estimate of fuel cell vehicle attributes is also provided. Most of the data provided are drawn from ongoing work by EEA for the DOE's Alternative Fuel Transition Model, or from a recently completed EEA analysis for the Office of Technology Assessment.

The specification of AFV attributes requires a series of supply side issues to be resolved largely based on the judgement of EEA. Essentially, manufacturers can choose to tradeoff first cost against vehicle range, performance and even emissions. The choice of such parameters should ideally be made by the demand forecasting model, but such capabilities are not yet available in demand forecasting models.

The first consideration in forecasting AFV demand is that all fuels are not well suited to all vehicle size classes. For example, the size and weight of CNG tanks make it a poor choice for small cars. Based on engineering considerations, EEA has estimated the likely combinations of fuel types and vehicle types that will be available in cars and light trucks. These combinations are shown in Tables E-10 and E11, respectively. It should be noted that are <u>no technical barriers</u> to any particular combination of fuel type and size class, and these favored combinations are based on EEA's judgement about market acceptability and economic barriers facing AFVs in each class.

A second and more important consideration is that vehicle price is a strong function of sales volume. There are significant fixed costs associated with the design, tooling and certification of an AFV model, and if a model has a sales volume of only a few hundred units per year, the fixed costs allocations to each unit are quite large. A typical (non-luxury) gasoline car model is produced at annual volumes of 100,000 to 200,000 units, while most current AFV model sales are only in the range of a few tens to hundreds of units per year. Since the supply and demand models are not interactive, the pre-specification of vehicle price involves estimating sales volumes. Other analysis by EEA suggests that economies of scale result in similar percentage price reduction for every order of magnitude increase in production volume. In this analysis, EEA has assumed that AFV's will be derived from gasoline vehicles and sales volume per <u>model</u> will be in the 2,000 to 3,000 range so that modest economy of scale is achieved, but the full extent is not, for the near term. Pricing at volumes of 20,000 to 30,000 units per year is also considered. Based on other analysis for DOE, EEA recommends that prices at intermediate volumes be scaled in proportion to the logarithm of sales.

EEA analysis for the DOE indicates that auto-manufacturers must anticipate a sales volume of about 2500 units per year of a given AFV model in order to enter the market. At much lower sales volumes in the range of a few tens of vehicles to a few hundred vehicles per year, automanufacturers have typically subcontracted the work to small conversion shops, or else these AFVs have been aftermarket conversions of existing gasoline vehicles. In general, manufacturers believe that most aftermarket conversions are not well engineered in terms of emissions, fuel economy, and safety, and often have poor performance at high or low ambient temperatures. However, these conversions are much cheaper than automanufacturer designed products at the same sales volume, so that an aftermarket conversion is usually sold at 250 units/yr at the same price as an OEM conversion sold at 2500 units/year. The poor quality is a deterrent to consumer purchase.

Table E-10: Alternative Fuel Type Potential Application by Size Class (Cars)						
	Mini/Sub Compact	Compact	Midsize	Large	Luxury	Sport
Alcohol Flex[4]	✗	✗	✗	✗	✗	✗
Methanol Neat	✗	✗	✗	✗		✗
Ethanol Neat		✗	✗	✗		
CNG Dedicated				✗		
CNG Bifuel				✗		
LPG Dedicated			✗	✗		
LPG Bifuel			✗	✗		
Electric	✗	✗				
EV/Hybrid		✗	✗			
Fuel Cell Methanol			✗	✗		
Fuel Cell Hydrogen			✗	✗		

The following sections summarize the changes required to develop each particular AFV type from a gasoline based car, which EEA believes will serve as the base design, since developing a unique "ground up" AFV design is not likely as long as AFV sales volumes per model are less than 10 percent of similar gasoline engine model sales. Manufactu-rer's may contemplate offering a unique "ground up" design only for EVs, if a specific model can be sold in volumes of 50,000 units per year or more, which appears unlikely to this time. In addition, only OEM products are considered so that quality issues do not influence purchase considerations.

As a result, future model specific improvements for all AFV types will follow those for gasoline vehicles, except for inapplicable technologies for a specific AFV type. These inapplicable technologies are recognized in the descriptions that follow. In addition, it should be emphasized that there is a sales volume based price affect, but there is no "learning curve" effect for all engine technologies that are very similar to gasoline engine technologies, namely engines for alcohol fuels, CNG and LPG. Learning curve effects for EVs and hybrid vehicles are primarily associated with future cost reductions in energy storage media, either batteries or ultracapacitors, and in power electronics. Learning curves also exist for CNG fuel tanks, but the cost reductions will be less dramatic than for EVs and hybrids.

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[4] Includes methanol/ethanol.

Table E-11: Alternative Fuel Type Potential Application by Size Class (Light Trucks)

	Mini-Utility	Compact Pickup	Compact Van	Compact Utility	Standard Pickup	Standard Van	Standard Utility
Alcohol Flex[5]	✗	✗	✗	✗	✗	✗	✗
Methanol Neat		✗	✗				
Ethanol Neat			✗				
CNG Dedicated		✗			✗	✗	
CNG Bifuel			✗		✗	✗	
LPG Dedicated		✗	✗		✗	✗	
LPG Bifuel		✗	✗		✗	✗	
Electric		✗	✗				
EV/Hybrid			✗	✗			✗
Fuel Cell Methanol		✗				✗	
Fuel Cell Hydrogen			?			?	

Each AFV type will require additional or specialized parts that result in variable cost increases, as well as fixed costs associated with:

- ENGINEERING
- TOOLING
- CERTIFICATION
- MARKETING

To the extent possible, total incremental AFV fixed costs per model have been identified. Table E-12 shows how the variable and fixed costs can be translated into a incremental retail price equivalent (IRPE) given a certain anticipated sales (or production) volume per model. These formulas have been used to develop retail price estimates. Ideally, the NEMS model should assume low sales volume prices, compute the actual sales, and iteratively check if the sales volumes predicted are in line with pricing assumptions.

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[5] Includes ethanol/methanol.

Table E-12: Conversion of Variable and Fixed Costs to IRPE	
Supplier costs to manufacturer	A
Total manufacturer investments	B
Unit cost of investment, C per production volume V	$\frac{B \times 1.358}{V \times 4.487}$
Automanufacturer Cost	A x 1.4 + C = D
IRPE	D x 1.25

FLEXIBLE FUEL AND DEDICATED ALCOHOL VEHICLES

These vehicles closely resemble the gasoline engine powered vehicle, and the modifications of a conventional vehicle to be either a flexible fuel vehicle (FFV) or dedicated alcohol fuel vehicle are relatively minor. At present, all alcohol vehicles are OEM products and no aftermarket conversions are expected. The most significant modifications are:

- Upgrade of the fuel tank and fuel lines materials to be corrosion resistant to alcohol
- New high flow fuel pump that can provide up to twice the flow rate of conventional pumps
- Modified fuel injectors and a new fuel/spark calibration for alcohol fuel
- Modifications to the evaporative emission control system to handle alcohol gasoline blends (FFV only)

The FFV also has a unique component, the fuel alcohol sensor that signals the engine electronic control system on the alcohol gasoline blend being used. The variable cost of all of the above parts is typically about $300 to $500 at low sales volume, with much of the cost associated with the fuel pump and fuel sensor. The high end of the range of costs is associated with converting a vehicle whose current fuel system requires significant materials changes, whereas the lower end would be for a vehicle whose current fuel system is corrosion resistant to alcohol.

Dedicated alcohol vehicles require similar changes but do not need the fuel sensor. If the engine is optimized for alcohol, it needs a new high compression ratio cylinder head, which partly offsets the cost of the sensor. Dedicated alcohol vehicle will have a simpler evaporative emission control system, although cost savings here are expected to be small. The net variable cost of a dedicated alcohol vehicle will be only slightly lower than that of an FFV and is estimated at $250 to 350 at low sales volume. Variable costs (which include supplier fixed costs) are expected to be reduced to half the low volume levels, i.e. $150 to 250, due to reduced per unit supplier costs, if volumes increase to 25,000 units/year.

Fixed costs for the automanufacturer are estimated at $7 to $8 million per model line, based on input from the manufacturers, for an assumed sales volume of 2500 units/year. However, significantly higher sales volume does not require much higher investment, and it is estimated that 25,000 units/year sales capability would require only an additional $2 million more to expand assembly capacity and enhance the marketing network.

Attributes of flexible fuel and dedicated vehicles are shown in Table E-13, relative to gasoline vehicle attributes. Prices are shown as if manufactures are pricing these vehicles as a standard product, (which they are clearly not) and EIA may wish to modify the prices to reflect current pricing. All of the improvements possible for conventional vehicles are applicable to FFV's and dedicated alcohol vehicles. At present, EEA believes that dedicated vehicles and FFVs operated on alcohol fuel may have small benefits in reactivity adjusted HC emissions (in the range of -10 to -20 percent) relative to an equal technology gasoline vehicle, but other emission benefits are negligible. In general, the range of prices shown at each sales volume are associated with vehicle size changes, with smaller cars at the low end of the price range, large trucks at the high end of the range, and mid-sized/large cars and compact trucks at the middle of the range.

Table E-13: Characteristics of Alcohol Fuel Vehicles Relative to Gasoline ICE's

	Methanol FFV	Ethanol FFV	Methanol Dedicated	Ethanol Dedicated
Horsepower	+4	+3	+8	+6
Range on M85/E85	-43	-27	-37	-24
Fuel Economy	+2	+1	+8	+4
Incremental Price ($)[6]				
@ 2,500 units/yr	1650-2000	1650-2000	1560-1820	1560-1820
@ 25,000 units/yr	410-500	410-500	370-425	370-425

CNG/LPG VEHICLES

CNG/LPG vehicles are the next step in complexity from an alcohol fueled vehicle for conversion from a conventional gasoline vehicle. The major difference is that the fuel tanks are more complex, heavy and expensive, especially for CNG. Currently, most CNG and LPG vehicles are aftermarket conversions, but the OEMs have recently entered this market with a range of new products.

Outside of the fuel tanks, engine and fuel conversion costs are quite similar to these for a dedicated

[6] Assumes manufacturer makes normal return on investment.

alcohol fuel vehicle. These include more expensive fuel lines, new fuel injectors and more expensive fuel injector drivers. The pump in an alcohol fuel vehicle is replaced by a pressure regulator, which can be a relatively expensive piece of equipment for a CNG vehicle that is certified to a stringent emission standard. Low pressure LPG pressure regulators are less expensive, but some manufacturers are experimenting with liquid LPG injection for optimal emission control. Engine improvements for both CNG and LPG systems are also similar, requiring revisions to the valve seats, pistons and rings and head gasket.

For dedicated systems, increases to the engine compression ratio (CR) by 0.5 to 1 point for LPG and 1.5 to 2 points for CNG are optimal. Such increases may, in turn, lead to revisions to the cooling system and air intake system. The increases in CR lead to a fuel economy benefit of and 4 and 8 percent for LPG and CNG, respectively.

Engine components and costs for a dual fuel system of high quality that is emission certified is estimated at $350 to 450. Engine improvements for dedicated CNG/LPG engines that are optimized will increase these costs to $500 to $600. However, there will be a cost savings of $350 associated with the elimination of the gasoline fuel system and evaporative system, for a net cost of $150 to 250. The costs are for volumes of 2,500 units/year and could decrease by 50 percent at 25,000 units/year, based on interviews with CNG system manufacturers.

Costs of fuel tanks are significant. For CNG, the incremental costs of tanks are estimated at $100-125 per gasoline equivalent gallon, and a typical tank for cars is about 9 gallons, while one for trucks is 12 gallons. Hence, CNG tank costs are $900 to 1125 for cars, and $1200 to 1500 for trucks at low volume. The tanks add about 150 lbs weight for cars and 200 lbs for trucks. LPG tanks cost approximately one-third as much as CNG tanks. One significant uncertainty is how much the cost of CNG/LPG tanks can decline as a function of volume. It has been estimated that costs will decline by 33% as sales volume increases from 2500 units/year to 25,000 units/year, but this figure may indicate benefits from "learning" as well.

Engineering and tooling costs for CNG and LPG vehicles are significantly higher than for alcohol fueled vehicles, because of the need to modify the body and chassis to accommodate the tanks, and the need to upgrade suspension tires and brakes to accommodate the increased weight. In addition, the vehicle will have to be crash tested due to the extensive changes to the fuel system, to verify system integrity. At low volume it has been estimated that engineering, tooling and certification costs per model for dual fuel vehicle are about $15 million. Additional engine engineering costs for a dedicated CNG/LPG vehicle are estimated at $3 million. Expansion of special assembly facilities to accommodate a volume of 25,000 units per year is estimated to cost an additional $5 million for facilities.

Costs and vehicle attributes for CNG/LPG vehicles are shown in Table E-14. In addition, it is assumed that future CNG/LPG vehicles will be certified as ILEVs for emissions to meet Clean Fleet and California requirements. As before, the range of costs span the size range of vehicles from small cars to large trucks. At sales volumes of a few hundred units per year, only aftermarket conversions are expected to be available at approximately the same price is OEM products at a sales volume of 2500 units/year.

Future improvements to CNG/LPG vehicles will not differ from those for gasoline vehicles, with the sole of exception of VVT (Variable Valve Timing). Pumping losses in CNG/LPG engines are lower because of the air displacement effect of gaseous fuels. EEA estimates that VVT benefits will be reduced to half its gasoline benefit when used in conjunction with these fuels.

ELECTRIC, FUEL CELL AND HYBRID VEHICLES

These vehicles are a significant departure from conventional vehicles in that their drivetrain and fuel system is very different from a gasoline engine and its fuel tank/fuel system. The pricing analysis of these vehicles reflects the fact that there are no electric vehicles (EVs) or Hybrid Electric Vehicles (HEVs) in production and that data must be extrapolated from current prototypes and pre-production vehicle models. Fuel cell powered vehicles are still at least a decade or two away from commercialization.

Electric Vehicles

In the electric vehicle, the engine is replaced by an electric motor and controller, while the gasoline tank is replaced by a battery. EEA analysis for the OTA for an EV with a production volume of 25,000 units/yr revealed a range of attributes that depend on battery technology. Table E-16 provides the data for four vehicle classes for several different batteries for the year 2005, which is believed to be the earliest point where relatively high EV production volume can be realized. However, the table assumes that a relatively high technology body would be used.

Table E-14: Attributes of CNG/LPG Vehicles Relative to Gasoline Vehicles				
	CNG Bi-fuel	**LPG Bi-fuel**	**CNG Dedicated**	**LPG Dedicated**
Horsepower	-15	-8	-5	0
Range	-50	-20	-40	-15
Fuel Economy (BTU equivalent)	-0	-0	+8	+4
Incremental Price[7]				
@ 2,500 units/yr	4750/5350	3550/3950	4840/5440	3670/3860
@ 25,000 units/yr	1825/2225	1085/1175	1695/2100	920/985

Note that range is based on an assumed tank size that holds approximately half the gasoline energy equivalent for CNG vehicles and 80 percent of the gasoline energy equivalent for LPG. Other tank sizes could be incorporated at different costs.

EEA believes that the Lead Acid battery is potentially the only viable near term solution. Some analysts claim that the Nickel Metal Hydride battery (Ni-MH) can became cost competitive at $200/kwh relative to a lead-acid battery at $125/kwh by the year 2002, but others believe that the Ni-MH batteries are more likely to cost $400/kwh initially. A range of 80 to 100 miles is the best that can be considered in the entire time frame to 2015, given the steep increase in costs to obtain a 200 mile range. Beyond 2005, the Ni-MH battery could be dominant, although it is very speculative to make such a prediction. Of course, all EVs are zero emission vehicles.

Electric vehicles can be conversions of existing gasoline vehicles, but the conversion is rather extensive. Essentially, the entire drivetrain must be replaced, necessitating removal of the gasoline engine and transmission. In addition, the fuel tank must be removed, and the vehicle equipped with batteries. The EV motor/controllers and batteries have very different characteristics of weight and size relative to the components displaced in a conventional gasoline car, so that the repackaging of these components, especially the battery, requires significant engineering and design effort. The conversion process typically utilizes a vehicle built without any of the gasoline vehicle's drivetrain and fuel systems, and such vehicles are referred to as gliders.

[7] Cars/Light Trucks.

Table E-16: EV Characteristics in 2005					
Battery (Scenario)	Range	Battery Weight (kg)	Total Weight (kg)	Energy Eff. (kwh/km)	Incr. Price (1994)
Subcompact					
Lead Acid (m)	80	612	1540	0.190	8,030
Ni-MH (m)	100	283	1010	0.116	13,575 (6631)*
Ni-MH (o)	200	823	1850	0.201	42,500
Na-S (o)	200	263	943	0.106	27,050
Intermediate					
Lead Acid (m)	80	830	2,031	0.250	10,900
Ni-MH (m)	100	370	1,335	0.153	17,900 (8835)[8]
Ni-MH (o)	200	1,075	2,430	0.265	55,675
Na-S (o)	200	343	1,250	0.141	35,500
Compact Van					
Lead Acid (m)	80	918	2,336	0.288	12,700
Ni-MH (m)	100	425	1,540	0.177	21,000 (10,600)*
Ni-MH (o)	200	1,234	2,800	0.305	64,400
Na-S (o)	200	394	1,440	0.162	41,220
Standard Pickup					
Lead Acid (m)	80	1,186	2,918	0.360	16,760
Ni-MH (m)	100	550	1,887	0.217	27,520 (14,070)*
Ni-MH (o)	200	1,598	3,527	0.384	83,820
Na-S (o)	200	510	1,764	0.199	53,800

Energy Efficiency is based on electrical consumption at wall plug. Price increment is relative to advanced conventional vehicle for the same scenario.

Purpose designed EVs have been displayed by some automanufacturers such as GM and BMW, but most industry analysts doubt that such vehicles will be produced at a production capacity level of less than 100,000 units/year because of the very high investment in the design, tooling and certification for a unique design. Indeed, GM officials have stated that they can never recover the $260 million invested in the design and engineering for the purpose-built "Impact" EV. Even at 100,000 units/year, media reports suggest that a purpose built EV would require investments similar to that for a conventional car (about $1 billion per model) but the incremental investment for a glider derived EV would be about one-tenth that amount.

For electric vehicles derived from a glider, investment costs have had to estimated since none of the

[8] Price if Ni-mH battery can be manufactured at $200/kwh.

manufacturers provided this information. Approximate estimates from published magazine articles and other anecdotal information support an estimate of $50 million in engineering, tooling, certification and launch cost for a production capacity of 2,500 units per year. This investment increases to $80 million for 25,000 units per year and $100 million for 100,000 units/year, based on the media reports discussed, as well as anecdotal information from the automanufacturers. However, the major capital expense is the construction of a battery plant, which is not treated here, since the battery is a "variable cost" to the automanufacturer. In addition, the same battery type or model can be used across different vehicle series and different automanufacturers.

In the near term (certainly to 2000 and perhaps to 2005), EEA believes that the only realistic battery option is the Advanced Lead Acid Battery. EEA interviewed the only manufacturer (Horizon) of such a battery that is nearing commercial production, and obtained costs at low volume production (of approximately 5000 vehicle battery packs per year) and at high volume (50,000 per year). Horizon's estimates for the high volume production rate battery was for a future unspecified date and may involve economies of both scale and learning, since such a battery has never been produced before.

The post-2002 estimate assumes emergence of the Nickel Metal Hydride battery, and its attributes have been estimated from current prototype performance. Although there is considerable uncertainty about its costs, it is assumed that the resulting EV will be cost competitive with a 2010 lead-acid battery powered EV, given a learning cost reduction schedule for the lead-acid battery. Although it is not necessary to specify the battery under this assumption to derive IRPE, it is necessary to do so to derive the characteristics of the EV in terms of weight, size and performance. EVs will also benefit from future improvements to weight, drag and rolling resistance.

For the computer model, it is assumed that all EV production will be based on a "glider" derived from a conventional gasoline car. The weight of the glider with no electrical components is estimated at 54 percent of the weight of the gasoline car. For an EV with performance levels equivalent to a gasoline car, battery weight (W_{Batt}) is given by:

$$W_{Batt} = \left[\frac{0.1 \frac{R}{S_3}}{0.9 - 0.15 \frac{R}{S_E}} \right] \cdot W_{Glider}$$

where R is the EV range (in km), S_E is the battery specific energy in watt hours per kilogram, and W_{GLIDER} is glider weight in kg. An advanced lead acid battery has a specific energy of 40 wh/kg, while the Nickel Metal Hydride battery has an S_E of 72. These equations are used to estimate battery weight.

The IRPE of the EV at 25,000 units/year is estimated based on the assumption that the cost of the electric motor and electronic controller will offset the cost of the gasoline engine, fuel system and emission control system while the cost of the battery will be the most significant cost increment to the EV. In volume production, Lead Acid batteries are expected to cost (the automanufacturer) $125 per kwh or $5 per kg. The Nickel Metal Hydride battery is initially expected to cost $400 per kwh or $28.80 per kg. These costs apply in 1998, but Ni-MH batteries in 2002 should decrease to about $250 per kwh.

Costs are expected to go down significantly with experience, but the "learning curve" is difficult to quantify objectively. Costs are expected to decline by 25 percent per decade based on interviews with battery manufacturers so that, for example, lead-acid batteries will sell for $94 per kwh in 2008. The IRPE calculation amortizes the $80 million in fixed costs as per the formula in Table E-12. Costs at low sales volumes of 2,500 units/year have been calculated externally, and in general, it has been found that an offset of $10,000 in IRPE provides a reasonable representation of the low volume sales price relative to the calculated high volume sales price.

Fuel-Cell Vehicles

In a full cell vehicle, the fuel cell is similar to the EV battery in that it supplies motive power to the motors. The sizing of the fuel cell is based on the continuous power requirement of the vehicle, but all other factors will be quite similar to those for an EV. However, the present state of development of fuel cells is in its infancy, and considerable development is required before the fuel cell can be commercialized. Fuel cell powered vehicles are also zero emission vehicles.

PEM Fuel cells can use only hydrogen as fuel, and hence, hydrogen must be either carried on board in liquid form in a cryogenic tank, or manufactured on board with a methanol reformer. The DOE is researching the PEM fuel cell and reformer, and the costs and weights of these components are based on very aggressive targets set by DOE, not on current costs which are two orders of magnitude above the targets. The DOE targets may be appropriate for fuel cells in the 2020 time frame.

Calculations by EEA for OTA, based on DOE cost and performance targets, indicate that fuel cell vehicles of either type will have weights approximately similar to these of conventional gasoline vehicles, so that the FEM utilizes a short-cut approach to fuel cell IRPE determination. It starts with the finding that weights are similar to derive the required power output of a fuel cell, which is 30 kw per ton of vehicle weight. Peak output requirements are assumed to be met by a high power lead acid battery with peak power capacity of 2/3 of the fuel cell output, and a specific power capability of 500 w/kg.

Costs are based on these power output estimates and it is assumed that fuel cells will be initially available at the cost of $450 per kw with a methanol reformer costing an additional $200 per kw in 2003. The costs are one order of magnitude higher than DOE targets but may be representative of prices that can be achieved in the short-term. The cost of a cryogenic hydrogen tank is estimated at about $3000, with only a weak dependence on size, at a sales volume of 25,000 unit/year. Costs of batteries are computed using the same methodology used to calculate EV battery costs.

Fixed cost amortization and low volume cost increases are assumed to be identical to those derived for EVs. However, the learning curve is expected to be very steep so that fuel cell/reformer costs decline 14 percent per year, to reach DOE targets by 2020. Fuel economy calculations are based on the details developed the OTA report, and are simply weight based for the purposes of the FEM.

Electric Hybrid Vehicles

Electric Hybrid Vehicles feature both an engine and an electric motor as part of the drivetrain, but there can be a wide variety of designs that allow for large variations in the relative sizes of the electric motor, i.c. engine, and electric storage capacity. Hybrids are often classified as series or parallel, and also as charge depleting or charge sustaining. Even within these four categories, manufacturers disagree about the optimal relative size of the engine versus the electric motor. Due to these uncertainties, EEA has selected one promising approach which is a series, charge sustaining hybrid, with an engine sized to be able to produce the continuous power requirement of 30 kilowatts per ton of loaded vehicle weight, as an example for determining the IRPE.

Since the calculations to derive hybrid vehicle characteristics are relatively complex, a reduced form based on EEA's work for OTA has been used. Most of the costs of the vehicles scale in approximate proportion to vehicle weight, so that the gasoline vehicle weight is used as an indicator, and the calculated midsized hybrid vehicle costs and fuel economy are used as a reference point for scaling. The IRPE of hybrid vehicles are scaled based on an expected midsized vehicle IRPE of $4400 in 2002 under a production rate of 25,000 units/year. A learning curve reduces these costs at 25 percent per decade, while low volume production at 2,500 units/year imposes an IRPE penalty of $10,000.

Series hybrid vehicles are expected to have 30 percent better composite fuel economy than current conventional gasoline cars. However, future engine improvements to reduce pumping loss and drivetrain improvements are not applicable to such vehicles, due to the electric drivetrain used. Emissions of these vehicles are expected to conform to California ULEV regulations, much like CNG vehicle emissions.

Attachment 2: Alternative Fuel Vehicle Model

Data Input Sources and Extrapolation Methodology

INTRODUCTION

This Attachment documents the AFV database used in the National Energy Modeling System Transportation Sector Model. The database includes the present values and forecast methodologies for several attributes for twelve EPA size classes of light-duty vehicles. These attributes apply to sixteen vehicle-technology types and three scenarios for nine census divisions of the United States.

DEFINITIONS

The vehicle EPA size classes are:

Cars

1. Minicompact
2. Subcompact
3. Compact
4. Mid-Size
5. Large
6. Two-Seater

Light Trucks

1. Compact Pickup
2. Standard Pickup
3. Compact Van
4. Standard Van
5. Compact Utility

6. Standard Utility

The attributes are:

1. Purchase price, **PSPR** (nominal $)
2. Fuel operating cost (new vehicle efficiency divided by fuel price), **FLCOST** (nominal $/gallon gasoline equivalent)
3. Vehicle range (miles between refueling) for dedicated fueled vehicles (alcohol dedicated, gaseous dedicated, EV, fuel cell methanol and fuel cell hydrogen technologies), **VRNG** (miles)
4. Top speed, **TPSD** (mph)
5. Acceleration from 0 to 30 mph, **ACCL** (seconds)
6. Dummy variable for gasoline capable vehicle with range > 250 miles (gasoline, diesel, fuel cell gasoline, alcohol flex, bi-fuel gaseous, and diesel hybrid technologies), **DR250** (0, 1 value)
7. Dummy variable for gasoline capable vehicle with range >200 miles (same technologies as #6), **DR200** (0,1 value)
8. Dummy variable for multi-fuel capability (alcohol flex and gaseous bi-fuel technologies), **MFUEL** (0,1 value)
9. Dummy variable for home refueling for EV's, **HFUEL** (0, 1 value)
10. Maintenance and battery replacement costs, **MAINT** (nominal $/yr)
11. Luggage space indexed to gasoline in in^3, **LUGG** (0 to 1 value)
12. Gasoline capable vehicle with range in excess of 250 miles (gasoline, diesel, fuel cell gasoline, alcohol flex, bi-fuel gaseous, and diesel hybrid technologies), **RGT250** (miles in excess of 250 miles)
13. Fuel Availability (Fraction of stations) indexed to gasoline, **FAVL** (0 to 1 value)
14. Fuel Availability^2 (Fraction of stations) indexed to gasoline, **FAVL2** (0 to 1 value)

The vehicle-technology types are:

1. Methanol Flex
2. Methanol Neat
3. Ethanol Flex
4. Ethanol Neat
5. CNG
6. LPG
7. Electric
8. Diesel Electric Hybrid
9. CNG Bi-Fuel
10. LPG Bi-Fuel
11. Fuel Cell Methanol
12. Fuel Cell Hydrogen
13. Fuel Cell Gasoline
14. Placeholder (empty)
15. Turbo Direct Injection Diesel
16. Gasoline (includes gasoline EV hybrid and direct injection gasoline technologies)

FORECASTING METHOD

The NEMS AFV submodule incorporates parameters and coefficients that were estimated by Argonne National Laboratory in cooperation with the U.S. Department of Energy's Office of Transportation Technologies, and EIA's Office of Integrated Analysis and Forecasting. The equation estimations used data from the National Alternative-Fuel Vehicle Survey conducted by Argonne and OTT.[9] The stated preference survey covered 47 of the lower 48 states in the U.S. excluding California. California was excluded because the University of California at Davis owns the rights to a similar survey for California. The intention was to combine the two surveys at some future point in time. The survey utilitzed three stages: 1) initial telephone interview of households, 2) customized questionnaire mailed to households, and 3) a second interview to review the answers to the questionnaire. The survey was taken from August 1995 to January 1996. 1904 respondents answers

[9]Tompkins, Melanie, David Bunch, Danilo Santini, Mark Bradley, Anant Vyas, and David Poyer, *"Determinants of Alternative-Fuel Vehicle Choice In The Continental United States,"* Presented at the 77th Annual Meeting of the Transportation Research Board, January 1998.

were received in stage 1) and 1149 respondents were contained in stage 2). Various combinations of vehicle prices, fuel prices, vehicle ranges, maintenance costs, performance levels, luggage spaces, and vehicle sizes were provided for each vehicle type. Gasoline, alcohol, CNG, LPG, and electric vehicles were contained in the survey. Additional information about the respondents included demographic data such as household structure, vehicle holdings, housing characteristics, employment and commuting patterns, household income, race, age, gender, and education level.

A multi-nomial logit model was estimated using maximum likelihood econometric techniques. The sample was divided into three car and three light truck size classes: 1) neighborhood electric vehicles, 2) small car (minicompact, subcompact, and two-seater sizes) and compact cars, 3) midsize and large cars, 4) compact and standard pickup trucks, and standard vans (which are considered work truck), and 5) compact and standard sport utility vehicles. Each size class has a corresponding equation which attempts to estimate the sale market share for all AFV's within a given size class, resulting in 6 separate equations. It was apriori assumed that valuation of the explanatory variables would differ by size class. During the estimation process, variables which were found to be not statistically significantly different from other size classes were combined. All of the equations were estimated simultaneously. It is important to note that all of the variables included in the estimation are not specific to vehicle size. Some of the variables such as the dummy variable for gasoline capable vehicles differ by fuel type. The statistical properties of the estimated equations are listed below.

Table E-17: AFV Estimated Equations and Statistical Properties of the National Alternative-Fuel Vehicle Survey (Version 33 from 8/7/98)

Variable	Size Class	Coefficient	Standard Error	Z statistic= Coefficient/Standard Error
Purchase price (nominal $) PSPR				
	nev	-7.07E-05	8.27E-05	-.855
	scar+ccar	-6.79E-05	1.32E-05	-5.145
	mcar+lcar	-4.11E-05	4.82E-06	-8.543
	cpickup+spickup+stdvan	-7.31E-05	1.17E-05	-6.263
	minivan	-1.13E-04	1.74E-05	-6.475
	suv+ssuv	-3.52E-05	9.55E-06	-3.689
Fuel cost (nominal $/mi) FLCOST				
	nev	-2.12E-01	5.70E-01	-.372
	scar+ccar	-1.12E-01	3.99E-02	-2.805
	mcar+lcar	-8.65E-02	2.77E-02	-3.122
	cpickup+spickup+stdvan	-5.37E-02	2.11E-02	-2.541
	minivan	4.22E-02	4.43E-02	.952
	suv+ssuv	-1.08E-01	2.51E-02	-4.295
Maximum range: dedicated AFV's (electric & gaseous) (miles) VRNG				
	nev	4.92E-03	3.65E-03	1.348
	scar+ccar	4.74E-03	2.23E-03	2.127
	mcar+lcar	3.05E-03	1.35E-03	2.252
	cpickup+spickup+stdvan	-2.25E-05	1.63E-03	-0.014
	minivan	5.22E-03	2.63E-03	1.985
	suv+ssuv	3.20E-03	1.47E-03	2.18
Gasoline capable range in excess of 250 miles (miles) RGT250				
	gasoline vehicle	-3.39E-03	1.39E-03	-2.436

	alcohol vehicle	-7.48E-04	1.56E-03	-0.478
	dual fuel gaseous	-2.47E-03	3.91E-03	-0.63
	hybrid EV	-4.05E-03	4.36E-03	-0.929
Dummy variable for gasoline capable range >250 miles (0 or 1 value) DR250		1.66E-01	1.38E-01	1.202
Acceleration time 0-30 mpg (secs) ACCL		-6.20E-02	2.40E-02	-2.59
Top Speed (mph) TPSD		3.04E-03	1.80E-03	1.694
Dummy variable for gasoline capable (0 or 1 value) DR200		1.23E+00	2.98E-01	4.121
Dummy variable for multi-fuel capability (0 or 1 value) MFUEL		-5.80E-01	1.41E-01	-4.122
Dummy variable for home re-fueling (EV's) (0 or 1 value) HFUEL		1.86E-01	1.36E-01	1.363
Maintenance & battery replacement costs (nominal $/yr) MAINT		-4.55E-04	1.75E-04	-2.605
Luggage space indexed to gasoline vehicle (0 to 1 value) LUGG		3.35E-03	1.35E-03	2.477

The original equation estimated also included the following variables to capture the effects of refueling infrastructure advances in the future. These variables although estimated simultaneously with the other variables, were not included in the AFV model because of the excessive feedback effects of lagged variables which are implicit in the formulation. Several of the AFV technology coefficients are also statistically insignificant. The infrastructure variable was named NUM and referred to the number of AFV's on road of a particular type.

Table E-18: Infrastructure Variable Excluded From the AFV Module

Variable	AFV Technology	Coefficient	Standard Error	Z Statistic
Number of AFV's on Road				
	dedicated EV	-2.85E-03	2.27E-03	-1.256
	hybrid EV	-2.29E03	3.32E-03	-0.69
	alcohol fueled vehicle	1.30E-03	5.57E-04	2.334
	dedicated gaseous vehicle	-3.23E-04	7.16E-04	-0.451
	dual fuel gaseous vehicle	1.36E-03	5.52E-04	2.46
Fuel Availability Capped at 10%: dedicated gaseous no home refueling		4.45E-02	2.14E-02	2.076

The fuel availability coefficients from the original NEMS model were used in replace of the fuel availability/infrastructure variables contained in the original National Alternative-Fuel Vehicle Survey.[10]

Table E-19: NEMS AFV Model Replacement Variables for Fuel Availability/Infrastructure

Fuel Availability (# stations/sq. 20 miles) (indexed to gasoline=1.0)	Variable	Coefficient	Standard Error	Z Statistic
	Fuel Availability	2.96	.52	5.7
	Fuel Availability^2	-1.63	.47	-3.5

Other changes were made to the original variables estimated from the National Alternative-Fuel

[10]Bunch, David, M. Bradley, T.F. Golob, R. Kitamura, and G.P. Occhiuzzo, *"Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Study,"* Transportation Research, Vol. 27A, pp. 237-253, 1993.

Vehicle survey estimates. The gasoline dummies for 1) gasoline capable vehicles with range greater than 250 miles, and 2) gasoline capable vehicles were both scaled relative to the gasoline vehicle range within each size class. Therefore, only the gasoline vehicle received the full dummy value of 1.0 times the coefficient. The other gasoline capable vehicles received the fraction of the dummy coefficient corresponding to its fraction of range as a percent of the gasoline vehicle range. Furthermore, at the first stage of the logit equation, in which gasoline vehicles and diesel vehicles are competed against a sales-weighted average AFV vehicle, the diesel vehicle was not given the gasoline capable dummy, but instead used the gasoline capable greater than 250 miles dummy variable. Conversely, at the first stage of the logit equation, the gasoline vehicle was provided with the gasoline capable dummy variable, but did not use the gasoline capable greater than 250 miles dummy variable. All of these adjustments were used to mitigate the penetration of diesel and gasoline vehicles. A large part of the reason for these changes to the originally estimated coefficients from the National Alternative-Fuel survey equations, result from the inclusion of diesel vehicles, which the survey did not originally include. Several other technologies included in NEMS, such as direct injection turbo diesels, diesel electric hybrids, and fuel cell vehicles, were not contained as a part of the survey. These technologies pose difficulties for the estimated equations because their vehicle attributes are usually outside of the normal range of values associated with AFV's.

DATABASE LIMITATIONS

There are some limitations which apply to the database and to its usage within a transportation choice model. They are discussed below.

MACROECONOMIC ISSUES

The database model is generally optimistic about the current rate of technological progress and innovation and assumes it will continue to grow progressively faster. Limitations in the database suggest that these forecasts may be overly optimistic in a macroeconomic sense.

- Diversion of Resources — the diversion of government and private sector resources toward alternative investments is not considered, i.e., large sums could go into infrastructure and mass transportation systems that are more efficient than any passenger vehicle alternative. Governmental and institutional budgets may be reduced significantly enough to impede future growth of AFV purchases; this especially applies to the Energy Policy Act of 1992, which by 1998 has not fulfilled it's mandate for federal fleet AFV purchases.

- Institutional Barriers — the created interests of significant economic or political actors, or groups of actors, could override market considerations for the benefit or detriment of any alternative technology or fuel.

- Environmental Barriers — one or more AFVs may receive significant opposition or backing purely for its environmental impact; moreover, public opinion as well as the environmental movement's preferences may shift in the near future, i.e., the environmental movement currently supports methanol-fueled vehicles, but that could change if a cleaner way to produce hydrogen for hydrogen-burning vehicles was found.

- Psychological Barriers — acceptance by the public is also a function of misperceptions and psychological factors, e.g., CNG, LNG, LPG and hydrogen may be perceived as dangerous to handle and thus avoided even if their safety records are objectively similar to that of gasoline.

- Information Barriers — accurate data do not exist for most of the exotic vehicle-fuel combinations (fuel cells, hybrid electric, etc.). Also cost and performance estimates for many of the emerging alternatives, especially electric vehicles, differ by a factor of 2-10 from source to source. In many cases, there is no clear basis for distinguishing among such inconsistencies.

DESCRIPTION OF VEHICLE TECHNOLOGIES

The AFV module currently analyzes 13 alternative-fuel technologies against a conventional gasoline powered vehicle[11] and diesel vehicle. Additional conventional and non-conventional technologies can be added to the analysis; however, for simplicity, conventional technologies are represented as a single category. This section of the report describes the characteristics of the alternative-fuel technologies as well as the criteria used in selection of alternative fuel-vehicle types.

Four primary technology selection criteria are employed for this study. The four criteria are the following:

- Vehicle operates utilizing a non-gasoline fuel or a significantly new engine technology.
- Technology holds the potential to penetrate the light-duty vehicle market by the year 2020.
- Technology possesses distinct fuel use, performance and/or cost characteristics relative to all other technologies considered.
- Data is available on important attributes for the vehicle technology.

Variations within each technology class based on vehicle subclass are not being analyzed as a distinct category but are incorporated into the collective category for the technology[12]. Future work in estimating market share growth for alternative-fuel technology may breakdown technology classes by engine and combustion technology; however, the complexity of such an analysis is unwarranted at the present time.

This study has identified 13 alternative-fuel technologies which have met the four criteria previously stated. Conventional gasoline technology has been grouped into one single category using average vehicle attributes taken across all conventional vehicles. Following is a list of the sixteen vehicle technologies incorporated in this study. The advantages and disadvantages of each of the individual technologies will be briefly described in the following sections.

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[11] This study assumes all gasoline powered internal combustion engines under a single technology category even though there is significant variation within gasoline fueled engines.

[12] Significant variations exist in the gasoline powered technology such as fuel injected engines versus carbureting engines; however, for simplicity all technologies utilizing a single fuel mix will be categorized together.

Gasoline Internal Combustion Engine Vehicles

Presently, the vast majority of transportation vehicles utilize an internal combustion engine (ICE) which was first patented in 1876 by Nikolaus Otto. The ICE is a heat driven engine which operates by mixing air and fuel vapor together, compressing the fuel mix in a cylinder, and igniting the fuel mix by means of an electric spark. The ignited fuel mix pushes a piston which in turn drives the vehicle[13]. Since the invention of the internal combustion engine the primary power source has been gasoline, although, many other fuels such as alcohols, natural gas and diesel can be utilized. It is speculated that if the discoveries of enormous petroleum deposits in Texas had not occurred during the early development years, the automobile would have developed as an alcohol vehicle rather than gasoline.

One of the primary advantages of conventional ICE vehicles is that economically these vehicles are inexpensive to operate due to the large development and refining infrastructure established for petroleum products. An abundance of petroleum deposits occur throughout the world and transportation of petroleum is not difficult in comparison to methanol and natural gas.

The conventional gasoline ICE vehicles are more harmful to the environment than the majority of alternative-fuel vehicles. Environmental concerns is one of the leading incentives for the development of alternative-fuel vehicles due to the problems associated with greenhouse gasses and urban ozone formation problems.

Diesel Vehicles

The diesel engine, like the gasoline engine, is an internal combustion engine which is heat driven from the ignition of diesel fuel in the cylinder which in turn drives the pistons. Unlike the gasoline ICE, a spark plug is not used to ignite the fuel mix but rather the combination of the compression and heat of the cylinder causes ignition of the fuel mix. Currently, diesel technology is advancing with the direct injection technology, in which a very lean diesel gas mixture is injected into the cylinder yielding approximately a 27% fuel economy improvement. Diesel technology at present receives an exemption from emissions standards for NOx and particulates. However, if direct injection engines become popular, it is uncertain if EPA will continue to allow the NOx and particulate exemptions in

[13] Glasstone, S., *Energy Deskbook*, Van Nostrand Reinhold Company, New York, 1983, pp. 364-368.

the future. Furthermore, EPA is current formulating their Tier II emissions regulations for both NOx and particulates, which may also limit the direct injection technology known for it's high emissions levels for both pollutants.

Ethanol Vehicles

Ethanol is a fuel which is currently being used to supply ethanol powered vehicles in a ratio of approximately 85 percent ethanol to 15 percent gasoline as well as a gasoline supply extender for conventional gasoline powered engines in a ratio of approximately 5 percent ethanol and 95 percent gasoline. This study is considering only ethanol vehicles (vehicles using the 85/15 percent mix) as a category separate from conventional vehicles. Two technology categories exist under the ethanol fuel heading. Ethanol Neat Vehicles use only ethanol fuel, and Ethanol Flex Vehicles have the ability to use any combination of gasoline and ethanol fuels.

Ethanol can be produced from food sources such as corn and sugar cane or from non-food biomass such as trees, grass, waste paper, and cardboard. Presently, approximately 95 percent of ethanol fuel being produced in the United States comes from corn. Neat ethanol engines are expected to produce a 30 percent increase in efficiency over conventional gasoline engines; however, ethanol fuel has a lower energy content of only 67 percent of gasoline. A variation in cost estimates for ethanol fuel production exist depending on the source material and the distillation process. The EPA estimates that the "gasoline equivalent" ethanol price using corn stock is between $1.47 and $2.07 per gallon[14].

Ethanol fuel provides several important environmental benefits over gasoline in both the consumption and production stages. Ethanol is produced from a renewable energy source such as corn or sugar cane, where as petroleum is a non-renewable energy source which could be depleted in the future. Ethanol fueled vehicles emit a lower amount of carbon dioxide, nitrogen oxide and hydrocarbons than gasoline[15]. The Environmental Protection Agency estimates that carbon dioxide emissions, the major component of "greenhouse gases", are reduced to zero using ethanol produced from corn or sugar

[14] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automobile Fuel*, April, 1990, pp. 15-22.

[15] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, pp. 20-21.

cane when considering the carbon reabsorption factor of corn during the growing stage[16].

Methanol Vehicles

Methanol fuel is similar in some respects to ethanol since it also is used as a gasoline extender in conventional gasoline engines and as a fuel in methanol engines. Presently methanol is mixed with gasoline in an 85 percent methanol/ 15 percent gasoline (M85) ratio and is consumed in a methanol engine. Two technologies exist for this analysis under the methanol heading; Methanol Neat which operates on M85 and Methanol Flex which has the ability to use any combination of M85 and gasoline depending on economic and availability factors.

Currently natural gas is the primary source of methanol although other materials such as coal, biomass and cellulose can be used. Methanol allows countries with excess natural gas supplies to export fuel without the expense of pipelines and LNG process. It is estimated that the wholesale price of methanol produced from natural gas is approximately $.40/gallon. However, because methanol has only about one half of the energy per gallon of gasoline, the cost per gasoline equivalent gallon is estimated at $.75[17].

Environmental advantages of methanol fueled vehicles are reductions in ozone formation, volatile organic compounds (VOC) and "greenhouse gas" emissions[18]. Ozone formation is a significant problem in urban areas linked to the emission of gasoline vehicles. Methanol emissions produce a lower photochemical reactivity than gasoline emissions; therefore, reducing the urban ozone formation problem. It is estimated that methanol vehicles emit 80 percent less VOC emissions than gasoline vehicles. Methanol vehicles emit increased volumes of formaldehyde and methanol gas which can be harmful in concentrated amounts. Further research is being conducted on the health risks associated with methanol and formaldehyde emissions.

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[16] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automobile Fuel*, April, 1990, pp. 49-50.

[17] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 28.

[18] Energy Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automobile Fuel*, April, 1990, pp. 15-18.

Electric Vehicles

Extensive alternative fuel vehicle research is now being done to improve electric vehicle performance. The primary obstacle of electric car development is battery technology. Various automobile manufacturers and research groups are concentrating on improving battery capabilities; however, at the present time battery technology limits electric vehicle range and performance attributes. For this reason electric vehicle motors have been combined with other conventional and non-conventional technologies in order to enhance vehicle performance. Technologies combined with electric motors include the internal combustion engine and gas turbine engine. This study will consider two technologies under the electric vehicle heading; electric, and diesel electric hybrid. Gasoline electric hybrid is contained in the gasoline conventional technologies.

The primary advantage of electric-powered vehicles is that they produce virtually no direct emissions at the point of consumption. Direct emissions produced by electric vehicles are largely hydrogen emissions released during the battery recharging stage. Although hydrogen is an explosive emission in high concentration, hydrogen poses no problem to atmospheric air pollution[19]. While electric vehicles produce almost no direct emissions there are emissions associated with the electricity production stage depending on the power source of the electricity generation. Centralized power plants located away from urban centers eliminate urban ozone formation problems and can effectively control emissions associated with fossil fuel consumption. Electric motors have the advantage over internal combustion engines (ICE) because electric motors do not idle when the motion is stopped as ICEs do thus eliminating the idling power loss which can be significant in urban transportation settings.

Considering present electricity prices, exclusive electric vehicles as an alternative to gasoline vehicles are not as cost effective as ethanol, methanol, and natural gas vehicles. Even though electricity as a transportation fuel delivers 50 percent more miles per Btu than other fuels, the current price of electricity makes electric fuel transportation notably more expensive than conventional vehicles[20].

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[19] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 21.

[20] Ibid, p.30.

Additionally, electric vehicle prices are much higher than conventional vehicles, because of the cost of the batteries, especially given their periodic (every 3 years for lead acid) replacement battery cost. Nickel metal hydride batteries extend the vehicle range of EV's by about 50%, but at approximately two times the cost of lead acid batteries.

Recently with the advent of the Toyota Prius, EV hybrid engine technology has arrived on the Japanese market. The Prius is scheduled to arrive in the U.S. market in the year 2000, according to Toyota's public annoucements. EV hybrid technology uses both conventional engine technology to run the vehicle to recharge the battery and operate at a steady state highway condition. The electric battery is only used during extreme power needs such as quick acceleration. While braking the vehicle, regenerative brakes are used to capture the energy lost during braking. EV hybrids can run on either gasoline or diesel fuel.

Compressed Natural Gas/Liquid Petroleum Gas Vehicles

Compressed Natural Gas (CNG) and Liquid Petroleum Gas (LPG) vehicles are grouped together in this summary because the engine technology is similar for the two vehicles utilizing different fuel sources. CNG vehicles have been in use for several decades in the United States while in other parts of the world they have been in operation since the 1930's[21]. The largest application of CNG vehicles has been in heavy-duty fleet vehicles because of the bulky natural gas storage tanks.

The CNG/LPG technology consists of a modified internal combustion engine connected to the fuel source in a closed system[22]. Because the fuel supply is in a gaseous state the entire storage engine system must be a closed system which eliminates the emissions problem of evaporating fuel during storage and refueling. The CNG/LPG engine produces higher thermal efficiencies than conventional gasoline engines; however, because of the additional weight involved with the fuel storage tanks the additional energy efficiencies are almost negated[23]. However; presently it is reported that natural gas

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[21] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel*, Volume II Heavy-Duty Vehicles, April 1990, pp. 1-2.4.

[22] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy*, December 21, 1990, pp. 90-91.

[23] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy*, December 21, 1990, pp. 90-91.

vehicle operation is less expensive than conventional gasoline vehicles. A survey of gas utilities taken by the Gas Research Institute indicated that the CNG price per gallon-equivalent of gasoline is $.85-$1.10. GRI reports that it's analysis indicates that CNG prices including compression costs and fuel taxes are 13 percent lower than gasoline cost for conventional vehicles[24].

Compressed natural gas and liquid petroleum gas vehicles are considered clean fuel vehicles because the fuel burns cleaner than conventional gasoline vehicles. Natural gas vehicles do not emit ozone formation emissions, however, these vehicles do emit a high amount of NO_x and methane which is an important contributor to greenhouse gases.

Fuel Cell Vehicles

The concept of fuel cells as a power source for transportation vehicles is similar to electric vehicle technology because an electric current powers a motor which drives the vehicle. The difference is that an electric vehicle runs off of a battery which is recharged periodically while a fuel cell is charged by a separate power source such as methanol or hydrogen. Fuel cell technology operates directly on hydrogen fuel and must have storage tanks for the hydrogen or have a reformer on board which runs on gasoline or methanol to create the hydrogen on demand. The first large scale applications of fuel cell technology were the Apollo and Gemini space missions which sparked interest in fuel cell technology in vehicle transportation.

Fuel cell technology has the advantage of higher conversion efficiency from the fuel source into electricity than a combustion engine. A large portion of the energy derived in a heat driven internal combustion engine is lost in the form of external heat which does not occur in the fuel cell technology. Fuel cell technology remains in the development stage and cost projections of transportation vehicles are extremely high. Further research may lower the costs of fuel cell technology; however, for now fuel cell technology seems unrealistic for large scale adoption until 2010. The Partnership for a New Generation of Vehicles (PNGV), a cooperative R&D effort by the U.S. government and the automotive industry, has spurred the fuel cell development. Many manufacturers have announced plans to have the fuel cell technology in a prototype by 2005 to 2006.

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[24] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 29.

Given mass production lead times of 4 to 6 years, fuel cells may not be available for the public until 2010.

VEHICLE PRICES

This section documents vehicle purchase prices and assumptions used to generate the endogenous calculation of vehicle prices. Vehicle prices are estimated for sixteen technologies and twelve EPA vehicle sizes, from 1990 through 2020, in thousands of nominal dollars.

The general approach is to establish current and ultimate price premia for AFV's (alternative fuel vehicles) over the price of a gasoline I.C.E. (internal combustion engine) vehicle, and to use an exponential decay function to simulate economies of scale in production (expressed as a compound percentage decline rate) in order to project each price premium as it approaches its ultimate value. The shape of the curve implied by the price decay is based on forecasted future price levels based on EEA's judgment where no data are available.

The current Fuel Economy Model (FEM) endogenously calculates vehicle prices, vehicle range, and fuel efficiency for new alternative-fuel vehicles (AFV's). The equations in FEM which correspond with the endogenous calculations for vehicle prices, vehicle range, and fuel efficiency are contained in Volume I. The following sections will provide the initial starting points for these vehicle attributes in 1990, as this is the beginning year of the model. All of the vehicle attributes vary across the 12 EPA size classes and are forecast through the year 2020. Each forecasted vehicle attribute is entered into the AFV technology equation in the AFV module to determine the sales shares among the technologies.

Because the FEM operates on 14 size classes in which vehicle prices, vehicle range, and fuel efficiency are endogenous calculated, once these three vehicle attributes are estimated, they are then converted to 12 EPA size classes. All other variables that are included in the AFV submodule are originally calculated based on the 12 EPA size classes. For comparative purposes, all vehicle attributes will be listed by 12 EPA size classes beginning in 1990.

VEHICLE PRICES

FEM vehicle prices are initially based on a salesweighted average by 14 vehicle size classes using auto industry trade sales data.[25] Although the FEM submodule estimates vehicle prices in $90, the AFV module converts the units to nominal dollars. Table E-20. lists the incremental cost of AFV's above a comparable gasoline vehicle for two production volumes, less than 2,500 units and less than 25,000 units. All vehicle production volumes between 2,500 and 25,000 units are scaled according to a logistic function. These incremental AFV vehicle costs are then scaled to each of the 14 FEM size classes and then allocated to 12 EPA size classes.

Table E-20: Initial Incremental AFV Costs Above A Comparable Gasoline Vehicle

Vehicle Technology	AFV Cars Incremental Cost ($90) for Production <2,500 units	AFV Cars Incremental Cost ($90) for Production <25,000 units	AFV Light Trucks Incremental Cost ($90) for Production <2,500 units	AFV Light Trucks Incremental Cost ($90) for Production <25,000 units
Gasoline	0.0	0.0	0.0	0.0
Flex-Fuel Methanol	1650	410	2000	500
Flex-Fuel Ethanol	1650	410	2000	500
Dedicated Methanol	1560	370	1820	425
Dedicated Ethanol	1560	370	1820	425
Dedicated CNG	4840	1695	5350	2100
CNG Bi-Fuel	4750	1825	3950	2225
Dedicated LPG	3670	920	5440	985
LPG Bi-Fuel	3550	1085	3860	1175
Dedicated EV	10000	0.0	10000	0.0
Diesel/EV Hybrid	10000	5000	10000	0.0
Methanol Fuel Cell	10000	0.0	10000	0.0
Hydrogen Fuel Cell	10000	0.0	10000	0.0
Gasoline Fuel Cell	10000	0.0	10000	0.0
Turbo Direction Injection Diesel	1200	800	2400	1600

[25]*Ward's AutomotiveYearbook*, Detriot, Michigan, various years.

Table E-21: Learning Curve Cost Reductions For Specific AFV's (fraction of initial incremental cost)

Year	Lead-Acid (~ 2.5%/yr)	Nickel Metal Hydride Ni-H	Market Share Ni-H (1.0=100%)	Methanol Fuel Cell ($/Kw ~ 14.2%/yr)	Hydrogen Fuel Cell ($/Kw ~ 14.2%/yr)	Gasoline Fuel Cell ($/Kw ~14.2%/yr)
1990	1.0000	5.0000	0.0000	9999.00	9999.00	9999.00
1991	1.0000	5.0000	0.0000	9999.00	9999.00	9999.00
1992	1.0000	5.0000	0.0000	9999.00	9999.00	9999.00
1993	1.0000	5.0000	0.0000	9999.00	9999.00	9999.00
1994	1.0000	5.0000	0.0000	9999.00	9999.00	9999.00
1995	1.0000	5.0000	0.0000	9999.00	9999.00	9999.00
1996	.9716	5.0000	0.0000	9999.00	9999.00	9999.00
1997	.9441	5.0000	0.0000	9999.00	9999.00	9999.00
1998	.9173	5.0000	0.0000	9999.00	9999.00	9999.00
1999	.8913	5.0000	0.0000	9999.00	9999.00	9999.00
2000	.8660	5.0000	0.0000	9999.00	9999.00	9999.00
2001	.8415	5.0000	0.0000	9999.00	9999.00	9999.00
2002	.8176	5.0000	0.0000	9999.00	9999.00	9999.00
2003	.7944	1.0000	.2000	9999.00	9999.00	9999.00
2004	.7719	.9716	.4000	9999.00	9999.00	9999.00
2005	.7500	.9441	.6000	650.00	450.00	750.00
2006	.7287	.9173	.8000	557.50	385.96	643.27
2007	.7081	.8913	1.0000	478.17	331.04	551.73
2008	.6880	.8660	1.0000	140.12	283.93	473.22
2009	.6685	.8415	1.0000	351.76	243.53	405.88
2010	.6495	.8176	1.0000	301.70	208.87	348.12
2011	.6311	.7944	1.0000	258.77	179.15	298.58
2012	.6132	.7719	1.0000	221.95	153.65	256.09
2013	.5958	.7500	1.0000	190.36	131.79	219.65
2014	.5789	.7287	1.0000	163.27	113.03	188.39
2015	.5625	.7081	1.0000	140.04	96.95	161.58
2016	.5625	.7081	1.0000	120.11	83.15	138.59
2017	.5625	.7081	1.0000	103.02	71.32	118.87
2018	.5625	.7081	1.0000	88.36	61.17	101.95
2019	.5625	.7081	1.0000	75.78	52.47	87.44
2020	.5625	.7081	1.0000	65.00	45.00	75.00

Vehicle prices are then adjusted to specific learning curves applied to specific costs for each technology. The subsequent cost reduction learning curves are list below.

All vehicle prices are adjusted each year to reflect increases/decreases in fuel economy due to increases/decreases in performance/horsepower relative to the equipment changes needed to meet a given performance level. Performance demanded by consumers is a function of fuel prices, income per capita, and the fuel economy of each size class (please see FEM submodule for more details).

FUEL EFFICIENCY

The AFV submodule uses fuel efficiency which is estimated in the FEM submodule (please see the FEM submodule for more details). AFV fuel efficiency is calculated relative to a comparable gasoline vehicle fuel efficiency for all 12 EPA size classes. Many of the advanced conventional technologies contained in FEM are also applicable to AFV's. After conventional technologies are applied to AFV's from conventional vehicles, specific AFV fuel efficiency technologies are used to account for individual AFV technology advances. These factors relative to gasoline are listed below. Adjustment factors include horsepower and weight differences.

Table E-22: Percentage Marginal Fuel Efficiency Adjustments Specifically for AFV's Relative To Gasoline Vehicles

AFV Technology	Initial Fuel Economy Adjustment	Horsepower Adjustments	AFV Weight Adjustments
Gasoline	0.00	0.00	0.00
Flex-Fuel Methanol	.02	.04	0.00
Flex-Fuel Ethanol	.01	.03	0.00
Dedicated Methanol	.08	.08	0.00
Dedicated Ethanol	.04	.06	0.00
Dedicated CNG	.08	-.05	.12
CNG Bi-Fuel	0.00	-.15	.15
Dedicated LPG	.04	0.0	0.00
LPG Bi-Fuel	0.00	-.08	0.00
Dedicated EV	0.00	0.0	0.00
Diesel/EV Hybrid	.60	0.0	.05
Methanol Fuel Cell	0.00	0.0	0.00
Hydrogen Fuel Cell	0.00	0.0	0.00
Gasoline Fuel Cell	0.00	0.0	0.00
Turbo Direct Injection Diesel	.35	-.05	.05

VEHICLE RANGE

The FEM submodule also estimates vehicle range endogenously across 12 EPA size classes. Vehicle range is calculated as a function of fuel tank size, fuel economy, and an initial adjustment for AFV range relative to gasoline (which is listed below).

Table E-23: Initial Vehicle Range Adjustment for AFV's Relative to Gasoline Vehicles

AFV Technology	Fraction of Gasoline Range
Gasoline	0.00
Flex-Fuel Methanol	-.43
Flex-Fuel Ethanol	-.27
Dedicated Methanol	-.37
Dedicated Ethanol	-.24
Dedicated CNG	-.40
CNG Bi-Fuel	-.50
Dedicated LPG	-.15
LPG Bi-Fuel	-.20
Dedicated EV	0.00
Diesel/EV Hybrid	.30
Methanol Fuel Cell	0.00
Hydrogen Fuel Cell	0.00
Gasoline Fuel Cell	0.00
Turbo Direct Injection Diesel	.35

The AFV submodule uses the vehicle ranges supplied by the FEM submodule and then converts them to conform to the following three range variables: vehicle range for dedicated vehicles (dedicated gaseous, dedicated alcohol, electric dedicated, and fuel cell methanol and hydrogen); a dummy variable for gasoline capable vehicles that have range greater than 250 miles; and a range variable for gasoline capable vehicles that have range in excess of 250 miles. Range in excess of 250 miles is calculated by subtracting 250 miles from actual range of the gasoline capable vehicle.

FUEL COST OF DRIVING PER MILE

Operating costs are accounted for in the AFV submodule by estimating the fuel cost of driving per mile. Fuel prices by census division, which come from the supply side NEMS models, are divided by the new car fuel economies for each AFV yielding a cost of driving per mile in units of nominal $/mi.

TOP SPEED

Data for top speed by AFV technology is developed by using the following relationship between top speed and horsepower per vehicle pound.

$$TPSD = 518.0 * (\frac{HPW}{WGT})^{.5}$$

where:

TPSD= top speed in mph.

HPW= vehicle horsepower

WGT=vehicle weight in lbs.

Horsepower and weight for each AFV technology and EPA size class for cars and light trucks is calculated in the FEM submodule. Top speed is an important choice variable for consumers because certain AFV technologies such as electric vehicles can only attain a given level of speed.

ACCELERATION FROM 0-30 MPH

Acceleration from 0-30 mph is included in the AFV submodule because technologies such as the electric vehicle can only accelerate at limited speeds. The acceleration time of 0-30 mph was chosen because the National Alternative-Fuel Survey revealed that consumers mainly care about the speed needed to accelerate from a standing position onto an entrance ramp of a highway. Acceleration times in units of seconds was estimated from the following equation:

$$ACCL = .312 * (\frac{HPW}{WGT})^{-.795}$$

MAINTENANCE AND BATTERY REPLACEMENT COST AND LUGGAGE SPACE

Maintenance and battery costs as well as luggage space attributes were developed by the U.S. Department of Energy, Office of Transportation Technologies.[26] These AFV attributes are held constant at the following levels:

Table E-24: Automobile Maintenance and Battery Replacement Costs ($96/yr)

AFV Technology	Mini	Subcompact	Compact	Midsize	Large	2-Seater
Methanol Flex	0	404	404	455	455	404
Methanol	0	404	404	455	455	404
Ethanol Flex	0	404	404	455	455	404
Ethanol	0	404	404	455	455	404
CNG	0	0	360	405	405	360
LPG	0	360	360	405	405	360
Electric	0	3380	3380	0	0	0
Diesel/EV Hybrid	0	420	420	473	473	420
CNG Bi-Fuel	0	0	360	405	405	360
LPG Bi-Fuel	0	0	360	405	405	360
Fuel Cell Methanol	0	0	420	420	473	473
Fuel Cell Hydrogen	0	0	360	405	405	360
Fuel Cell Gasoline	0	0	420	473	473	420
Turbo DI Diesel	0	0	400	450	450	400
Gasoline	400	400	400	450	450	400

[26]U.S. Department of Energy, Office of Transportation Technologies, *Program Analysis Methodology: Quality Metrics 99*, Washington DC, December 1997.

Table E-25: Light Truck Maintenance and Battery Replacement Costs ($96/yr)

AFV Technology	Small Pickup	Large Pickup	Small Van	Larg Van	Small Utility	Large Utility
Methanol Flex	505	505	450	505	450	450
Methanol	505	505	450	505	0	0
Ethanol Flex	505	505	450	505	450	450
Ethanol	505	505	450	505	0	0
CNG	450	450	405	450	0	0
LPG	450	450	405	450	0	0
Electric	3400	0	3390	0	0	0
Diesel/EV Hybrid	0	0	473	0	473	473
CNG Bi-Fuel	450	450	405	450	0	0
LPG Bi-Fuel	450	450	405	450	0	0
Fuel Cell Methanol	450	0	405	0	0	0
Fuel Cell Hydrogen	0	0	405	0	0	0
Fuel Cell Gasoline	0	0	405	0	0	0
Turbo DI Diesel	500	500	450	500	450	450
Gasoline	500	500	450	500	450	450

Luggage space is indexed to gasoline vehicles. Luggage space is an important variable for consumers, because electric vehicle batteries and CNG and LPG fuel tanks utilize the backseat of most vehicles.

Table E-26: Automobile Luggage Space Relative to Gasoline (Indexed to 1.0=gasoline)

AFV Technology	Mini	Subcompact	Compact	Midsize	Large	2-Seater
Methanol Flex	0.00	1.00	1.00	1.00	1.00	1.00
Methanol	0.00	1.00	1.00	1.00	1.00	1.00
Ethanol Flex	0.00	1.00	1.00	1.00	1.00	1.00
Ethanol	0.00	1.00	1.00	1.00	1.00	1.00
CNG	0.00	0.00	.75	.75	.75	.75
LPG	0.00	.75	.75	.75	.75	.75
Electric	0.00	.70	.70	0.00	0.00	0.00
Diesel/EV Hybrid	0.00	.90	.90	.95	.95	.95
CNG Bi-Fuel	0.00	0.00	.75	.75	.75	.75
LPG Bi-Fuel	0.00	0.00	.75	.75	.75	.75
Fuel Cell Methanol	0.00	0.00	.80	.80	.80	.80
Fuel Cell Hydrogen	0.00	0.00	.75	.75	.75	.75
Fuel Cell Gasoline	0.00	0.00	.80	.80	.80	.80
Turbo DI Diesel	0.00	0.00	1.00	1.00	1.00	1.00
Gasoline	1.00	1.00	1.00	1.00	1.00	1.00

Table E-27: Light Truck Luggage Space Relative to Gasoline (Indexed to 1.0=gasoline)

AFV Technology	Small Pickup	Large Pickup	Small Van	Large Van	Small Utility	Large Utility
Methanol Flex	1.00	1.00	1.00	1.00	1.00	1.00
Methanol	1.00	1.00	1.00	1.00	0.00	0.00
Ethanol Flex	1.00	1.00	1.00	1.00	1.00	1.00
Ethanol	1.00	1.00	1.00	1.00	0.00	0.00
CNG	.75	.75	.75	.75	0.00	0.00
LPG	.75	.75	.75	.75	0.00	0.00
Electric	1.00	0.00	1.00	0.00	0.00	0.00
Diesel/EV Hybrid	0.00	0.00	1.00	0.00	1.00	1.00
CNG Bi-Fuel	.75	.75	.75	.75	0.00	0.00
LPG Bi-Fuel	.75	.75	.75	.75	0.00	0.00
Fuel Cell Methanol	.80	0.00	.80	0.00	0.00	0.00
Fuel Cell Hydrogen	0.00	0.00	.75	0.00	0.00	0.00
Fuel Cell Gasoline	0.00	0.00	.80	0.00	0.00	0.00
Turbo DI Diesel	1.00	1.00	1.00	1.00	1.00	1.00
Gasoline	1.00	1.00	1.00	1.00	1.00	1.00

ADDITIONAL DUMMY VARIABLES

There are three additional dummy variables in the AFV submodule which are used to determine the sales of AFV's. These consist of a dummy variables for a) gasoline capable vehicles, b) multi-fuel capable vehicles (flex, bi-fuel technologies), c) electric vehicle capable of home refueling.

VEHICLE EMISSIONS

This section describes vehicle emissions from conventional and ATF vehicles over time.

INDEX APPROACH

The general approach uses an index value tied to the impact-weighted emissions from mid-size gasoline vehicles. In each year from 1990-2030, the emissions impact from the base-case gasoline vehicle is estimated. As gasoline vehicle emissions decline (e.g., due to reformulation), the absolute emissions level declines but the index value remains constant (at 1.0). The emissions impact of the alternative fuels is benchmarked against the absolute level to create the index value for the alternatives. If the emissions of an AFV declines faster than that of the gasoline vehicle, the emissions index for that AFV will decline. If the emissions of an AFV increases or declines less rapidly than that of the gasoline vehicle, the emissions index for that AFV will increase. The technology choice module can make use of this relative indexing in annually selecting vehicle types.

The weight given to emissions and emissions indexing in the technology choice module is outside the scope of this database. Whether decisions will ultimately be made with respect to some threshold emissions level is also not considered.

The emissions index is constructed from the following inputs:

- Current emissions from a mid-size car for five pollutants (CO, CO_2 , NO_x, methane, and NMHC) in grams/mile for 16 vehicle types. See Table E-28.

- Minimum possible emissions by 2030 for the same pollutants for the same vehicle types. See Table E-29.

- Annual simple percentage decline in emissions towards the minima, same vehicle types.

- Impact-weighting of the five pollutants on health and environmental criteria.

The index constructed from these data is necessary because the impact on human health and the environment from a gram of one pollutant is not equivalent to the impact of another pollutant. This non-equivalence is particularly apparent when one compares the typical emissions of NO_x (about 1 gram/mile) to that of CO_2 (about 450 grams/mile). Clearly, CO_2 is not 450 times more hazardous to health or the environment than NO_x. Thus, a weighting scheme (i.e., an index) must be constructed to properly compare the overall emissions index.

Table E-28. Base Mid-Sized Vehicle Emissions (Grams/Mile, 1990)

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2	ASSUMPTIONS AND EXPLANATIONS
Gasoline	9.00	1.00	0.00	1.03	452	Representative vehicle for size category. Standard catalytic converter.[27]
Diesel	3.40	0.41	0.00	1.00	450	Representative vehicle for size category. Consistent with data entered under gasoline. Standard catalytic converter.
Ethanol Flex	2.00	0.60	0.00	1.10	435	Consistent with data entered under gasoline and diesel. Retrofitted representative vehicle for size category. Generally higher NO_x than gasoline and diesel due to higher combustion temperature. Formaldehyde not included for methanol emissions.
Ethanol Neat	1.57	0.36	0.00	1.10	429	
Methanol Flex	1.75	0.29	0.00	1.10	447	
Methanol Neat	1.50	0.20	0.00	1.10	450	
Electric	0.00	0.00	0.00	0.00	0.00	Near zero emissions. Rounded off for manageability.
Electric Hybrid/ Large ICE	2.00	0.10	0.00	0.20	90	Due to smaller size and less use, i.c.e.'s emissions are ¼ or less of a conventional engine.
Electric Hybrid/ Small ICE	1.00	0.05	0.00	0.10	45	Due to smaller size and less use, i.c.e's emissions are ½ of large i.c.e.'s
Electric Hybrid/ Gasoline Turbine	0.50	0.03	0.00	0.06	25	Near zero for electric part. See TURBINE entry below. Due to less use and smaller size emission's are about ¼ of conventional turbine's.
CNG	0.30	0.23	1.20	0.97	419	Representative vehicle, consistent with alcohol and gasoline vehicles selected above.
LPG	0.28	0.29	0.00	0.59	437	
Turbine/Gasoline	2.00	0.10	0.00	0.25	100	Theoretically very low emissions, around ¼ of conventional fuel (gasoline or CNG respectively) vehicle.
Turbine/CNG	0.08	0.06	0.35	0.40	95	
Fuel Cell/Methanol	0.00	0.00	0.20	0.01	0.01	Near zero emissions. Small methane figure for methanol vehicle.
Fuel Cell/Hydrogen	0.00	0.00	0.00	0.01	0.01	

[27] For all technologies, pollution produced by the power source or fuel production process is not included.

Table E-29. Minimum Possible Emissions, Mid-Size Vehicle (Grams/Mile, 2030)

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2	ASSUMPTIONS
Gasoline	1.70	0.04	0.00	0.20	250	Advanced catalytic converters and reformulation.[28]
Diesel	1.25	0.04	0.00	0.20	250	
Alcohol Fuels: Flex & Neat	1.00	0.04	0.00	0.20	250	Advanced catalytic converters.[29]
Electric	0.00	0.00	0.00	0.00	0.00	Power source and accidental leakage not included.
Electric Hybrid/ Large ICE	0.40	0.01	0.00	0.04	60	Due to less use and smaller size, ICE's emissions are ¼ or less of conventional engine.
Electric Hybrid/ Small ICE	0.20	0.01	0.00	0.02	30	Due to smaller size, ICE's emissions are ½ of large ICE hybrid.
Electric Hybrid/ Gasoline Turbine	0.01	0.00	0.00	0.01	12	Advanced catalytic converter and reformulation.
CNG	0.20	0.01	0.20	0.20	250	Advanced catalytic converter.
LPG	0.10	0.04	0.00	0.20	250	
Turbine/Gasoline	0.50	0.02	0.00	0.05	25	Advanced catalytic converter and reformulation.
Turbine/CNG	0.05	0.00	0.05	0.05	25	Advanced catalytic converter.
Fuel Cell/Methanol & Hydrogen	0.00	0.00	0.00	0.01	0.01	Negligible emissions.

[28] For all technologies, emissions from fuel source and accidental leakage is not included.

[29] For ethanol, the 30 to 50% emissions reduction must be weighed against the considerable CO, CO_2 and nitrogen compounds produced by growing, fertilizing, harvesting, drying and transporting the crops to produce the fuel. EPA estimates the pollution created by producing and burning a gallon of ethanol is up to six times as much as producing and burning a gallon of gasoline. However, aldehydes are not produced (Frank, August 1992, p.106).

IMPACT WEIGHTING

The weighting scheme assumes that all impacts will be in the area of health (85% of the decision) or environment (15%) and will be based on each pollutant's contribution to impacts in those areas. For example, CO_2 has an impact on the environment but little or no impact on health. For CO, the reverse is true. Note that we are not considering health impacts derived from environmental impacts as health impacts. We are using the more conventional understanding that, for example, CO_2 is not considered a respiratory hazard (health) but is a greenhouse gas (environment).

In general, the reasoning behind the weightings is as follows:

- **Carbon Monoxide (CO) —** A moderate health hazard for its role in surface-level ozone creation; its environmental effect is negligible.

- **Non-Methane Hydrocarbons (NMHC) —** Serious health hazard for its significant role in surface-level ozone creation; its environmental effect is negligible.

- **Methane (Met) —** Important greenhouse gas; negligible health threat.

- **Nitrogen Oxides (NO_x) —** Serious health hazard for their role in surface-level ozone creation; also a significant greenhouse gas.

- **Carbon Dioxide (CO_2) —** Statistically insignificant health impact but some greenhouse impact.

The choice of the five pollutants (CO, CO_2, NO_x, methane, and NMHC) was based partly on the availability of detailed technical literature and partly on SAIC's judgment about the pollutants likely to affect vehicle choice and public policy in the coming decades. Additional pollutants, notably aldehydes and particulates, could have been added. The ultimate selection of five pollutants was based on computational tractability. The specific inclusion of methane and non-methane hydrocarbons was based on the need to distinguish natural gas-fueled vehicles based on smog-related and non-smog-related emissions. The impact of the various pollutants per unit emitted is assumed not to change over time.

Table E-30. Pollutant Impact Weighting Factors (Health vs. Environment)

IMPACT	WEIGHT	CO	NMHC	MET	NO_x	CO_2
Health	0.85	0.02	0.44	0.00	0.39	0.00
Environment	0.15	0.00	0.00	0.09	0.06	0.0005

The database treats electric vehicles as zero-emissions vehicles (ZEVs) in accordance with California regulations and shows them with zero emissions. Powerplant emissions are not included in the database. Emissions for the gas turbine engines are generally guesses. Emissions levels for the fuel cells are approximately zero, except for NO_x. The emissions for converting coal or natural gas to methanol or hydrogen for use in the fuel cells are not included. Similarly, emissions from ethanol exclude the CO, CO_2, and nitrogen compounds emitted during growing, fertilizing, harvesting, drying, and transporting the crops. Emissions and leakage from tanks (e.g., CNG and hydrogen releases) are also not considered.

DECLINES IN EMISSIONS OVER TIME

The simple annual percentage rate at which the vehicle emissions decline is based on an extensive review of the literature for both the vehicles and the fuels. The decay rates are provided in the following table.

Table E-31. LDV & AFV Emissions Decay Rates

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2
Gasoline & Diesel	10.0%	10.0%	0.0%	5.0%	0.0%
Alcohol Fuels/Neat & Flex	5.0%	10.0%	0.0%	5.0%	0.0%
Electric Hybrids/ICE & Turbine	0.0%	0.0%	0.0%	0.0%	0.0%
CNG	5.0%	10.0%	10.0%	5.0%	3.0%
LPG	5.0%	10.0%	0.0%	5.0%	3.0%
Turbine/Gasoline	10.0%	10.0%	0.0%	5.0%	0.0%
Turbine/CNG	5.0%	10.0%	10.0%	5.0%	3.0%
Fuel Cell/Methanol & Hydrogen	0.1%	0.1%	0.1%	0.1%	0.1%

In general, the following factors were considered.

- **Gasoline —** Development of upgraded on-board computers for more precise spark timing and fuel injection (so gasoline burns more completely and less HC's escape); widespread use of catalytic converters that will eliminate up to 99% of CO and NO_x pollution by electronically preheating before a car starts; consequent increase in CO2.

- **Electric —** Assigned zero emissions in isolation of power source, therefore decay function is also zero. Even if power source is included there will be dramatic reductions compared to gasoline emissions, depending on fuel burned (natural gas or coal) to generate power. Improvements in emission controls at the source are expected to keep electricity ahead of gasoline.

- **Electric Hybrid/Gas Turbine —** Gas turbine would emit insignificant amounts of pollutants, so they may not need a catalytic converter. Without including power source, the electric part would have zero emissions (see above paragraph.) Although not yet engineered as such, turbine technology has been fully developed.

- **Turbine/CNG —** Widely used in other applications, with well-known emissions. For passenger vehicle applications this technology will emit insignificant amounts of pollutants and may not need catalytic converters.

SOURCES AND REFERENCES:

- **Gasoline —** Clean, highly efficient vehicles such as the M-Miller Cycle engine vehicle are being developed in Japan (Japan 21st, 1992).

- **Methanol Neat —** A dedicated vehicle has higher compression ratios, thus higher heat and NO_x than gasoline I.C.E.; high level of formaldehyde (Oil & Gas, Dec 1991, p.59); high level of carcinogen formaldehyde (Oil & Gas, Dec 1991, p.59).

- **CNG —** The cleanest running nonelectric production vehicle available today full-size Dodge van (Frank, August 1992, p.105). CO level is 1/2 to 1/10 lower, but NO_x is higher due to higher peak combustion temperature in the presence of excess oxygen (Oil & Gas, Dec 1991, p.59).

- **LPG —** Low CO and HC, higher NO (Oil & Gas, Dec 1991, p.60). In the 1992 Ford F-700 Medium Duty Truck, HC and NO_x are significantly lower than their conventional equivalent, while CO emissions are comparable (NREL, 1992, On line).

- **Fuel Cell/Hydrogen and Methanol —** Would meet California's no-emissions requirements for 1994 (McCosh, 1992, p.29); cleanest emissions of any fuel; emissions are water and a low quantity of NO_x (SAIC/report, 1991, p.22); temperature of the electrochemical reaction is low enough to keep NO_x from being a problem (Romano, 1989, p.75).

  Production process reverses gains in emissions; CO2 & NO_x are byproducts of hydrogen production (Ondrey, 1992, p.30).

  Japan in investing in hydrogen-burning vehicles that are far cleaner than any other AFV (Maruyama, 1991); environmentally friendly HR-X by Mazda, a prototype with a hydrogen-burning rotary engine developed already (Japan 21st, 1992).

- **Gasoline —** Upgraded on-board computers for more precise spark timing and fuel injection; future catalytic converters may eliminate 99% of pollution by electronically preheating before a car starts (Woodruff, 1991, p.56).

  Possibilities of catalytic converters: Ford's 1993 Escort/Mercury Tracer models pass California's 1994 TLEV standard; Corning's EHC prototype passes 1997 ULEV standard (Cogan, September 1992, ps.35); 96% HC and 76% NO_x reduction comparing 1992 to 1960's vehicles (Frank, August 1992, p.103); improvements in refueling connection (Oil & Gas, Dec 1991, p.38). By 2003 the CAA could require 25% of all US cars to cut HC by 40%, and NO_x by 50%. By 2006 100% of US cars must meet that standard (Woodruff, 1991, p.59).

- **Electric —** Dramatic reductions compared to gasoline emissions depending on fuel burned (natural gas or coal), emissions controls at the power plant and type of generating equipment (Frank, August 1992, p.105).

- **Electric Hybrid/Turbine —** No direct reference. See relevant entries ELECTRIC above and TURBINE below.

- **CNG —** Considerable improvement potential for emissions in three areas: fuel metering and mixing, lean/dilute combustion systems, catalytic converters (Weaver, 1991, ps.4-7).

- **Turbine/Gasoline —** Gas turbine would emit insignificant amounts of pollutants, may not need a catalytic converter (The Economist, September 28, 1991, p.95).

- **Fuel Cell/Hydrogen —** Hydrogen already is the cleanest fuel available; only emissions are water and small quantities of NO_x (SAIC/report, 1991, p.22).

REGIONAL DIFFERENCES, ASSUMPTIONS, AND CRITERIA

Regional fuel prices are calculated by adding a percentage price differential to the national average retail prices found in the preceding table. The price differentials for each region shown in Table E-32 are based on factors such as proximity or access to major ports, production fields, refineries, state/regional consumer price index, adequate infrastructure, local producer and government support. These factors, assumptions and caveats are discussed after the table. The subsequent notes raise questions about the sustainability of these differences in a national market.

Table E-32. Regional Fuel Price Differences

FUEL TYPE	PERCENTAGE DIFFERENCE BY REGION								
	NE	MA	SA	ENC	ESC	WSC	WNC	MTN	PAC
Gasoline	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Diesel	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Ethanol	0.075	0.0375	0.037	0	0	0.01	0	0.0375	0.05
Methanol	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
CNG	0.05	0.025	0.0375	0.025	0.025	0	0.025	0	0.025
LPG	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Electricity	0.1	0.05	0.025	0.01	0.025	0.01	0	0	0.0375
Hydrogen	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01

Abbreviations:

NE	New England
MA	Mid Atlantic
SA	South Atlantic
ENC	East North Central
WSC	West South Central
WNC	West North Central
MTN	Mountain
PAC	Pacific

EXPLANATIONS

- **Gasoline —** In the U.S. national market gasoline prices are essentially the same.

- **Diesel —** In the U.S. national market diesel prices are essentially the same.

- **Ethanol —** Mainly produced from corn in Midwest states; the regions that are part of it, or closest to it, enjoy lower prices due to advantages such as access, convenient transportation, and local support (i.e., state subsidies, farmers interests).
- **Methanol —** Mostly imported, therefore regions enjoying proximity and easy access to major ports and processing infrastructure, i.e., Los Angeles and New Orleans, would have a price advantage. The Pacific region also benefits from California's acute interest in this fuel, i.e., special incentives from the state. Inflexible infrastructure and the high cost of living in NE and WNC explain higher prices in those regions.

- **Electricity —** Regions with access to relatively abundant and cheap power produced by hydroelectric and coal-fired power plants benefit, e.g., WNC, WSC, MTN, and ENC. More expensive power from regions without low-cost fossil fuels drives prices up in NE and MA.

- **CNG —** Proximity to the rich fields in WSC and MTN benefits those regions and ESC, WNC, ENC and PAC. Competing imports benefit areas near major ports, i.e., PAC, ESC. The high cost of living and inaccessibility to fields drive prices up in NE.

- **LPG —** Access to competitive imports and refineries benefits PAC, ESC and ENC. Local production and support would benefit ENC and PAC. Higher transportation costs, infrastructure inflexibility and higher cost of living puts NE at a disadvantage.

- **Hydrogen —** Access to abundant raw materials, i.e., especially low-cost electricity benefits such regions as PAC, ENC, SA, WSC. Infrastructure and local support also push prices down in PAC. WSC, and MTN.

IMPORTANT ASSUMPTIONS AND CAVEATS

- Regional fuel price differences may persist due to transportation costs from producing or importing regions. These differences, however, are likely to be no more than $.05/gallon equivalent and are generally less than differences in state excise taxes.

- Differences in state excise taxes within a region can easily exceed differences in transportation costs from region to region.

- Electricity is shown at an average price. Off-peak electricity will cost less and on-peak electricity will cost much more. If EV sales are induced with the promise of daytime refueling at the office, much higher charges than those shown on the table will apply.

FUEL AVAILABILITY

This section documents fuel availability in the database. The output is fuel availability as a percent of gasoline availability for eight fuels, for nine regions, from 1990 through 2030, through three penetration scenarios (base, high, low).

The general approach is to determine current and ultimate fuel availability as a percentage of gasoline availability (assumed to be 1). A number of current fuel availability factors were considered in creating a percentage index for each fuel. Projected availability is determined by changes in these factors over time, which are represented by an exponential rate of closure in the current availability gap between gasoline and each of seven alternative fuels. The rate of closure changes for each of three penetration scenarios (base, high, low).

The data reported in this section are uncertain and of questionable usefulness due to the uncertain specification of availability in the model. The values reported in this section must be read in the light of the subsequent extended comments on modeling problems related to fuel availability.

The inputs used to forecast fuel availability are:

- Current regional fuel availability factors, as a percentage of gasoline availability, for all fuels.
- Fuel availability growth factors, represented as an exponential rate of closure in the availability gap.

The approach has the following advantages:

- Projected alternative fuel availability index values should be relatively consistent vis a vis gasoline and other ATF availability indices.
- Updating and revising figures based on future developments are facilitated.

CURRENT FUEL AVAILABILITY

Current alternative fuel availability regional differences are expressed as a percentage of gasoline availability in the base year 1990 as shown in the following table. Important limitations on these values and their usage are subsequently discussed.

Table E-33. Base Year (1990) Fuel Availability, by Region

FUEL TYPE	NE	MA	SA	ENC	ESC	WNC	WSC	MTN	PAC
GASOLINE & DIESEL	1	1	1	1	1	1	1	1	1
ETHANOL	0.01	0.02	0.02	0.1	0.02	0.02	0.02	0.05	0.05
METHANOL	0.01	0.05	0.02	0.02	0.02	0.02	0.01	0.05	0.1
CNG	0.01	0.02	0.02	0.05	0.02	0.02	0.05	0.05	0.05
LPG	0.01	0.02	0.02	0.05	0.02	0.02	0.1	0.05	0.1
ELECTRICITY	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
HYDROGEN	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

FUTURE AVAILABILITY

Changes in infrastructure and other growth factors that are demanded by an economically significant ATF are discussed in this section, along with pertinent assumptions and caveats.

Future availability is determined by changes in the regional availability factors outlined in the previous section. Such changes affect the differences between gasoline and each ATF, so they are represented by an exponential rate of closure of the availability gap between gasoline and each ATF.

GASOLINE INFRASTRUCTURE AND OTHER GROWTH FACTORS

There are roughly a million gasoline stations in the United States at the present time. For any ATF to be accepted by the public a certain threshold of availability must be reached (aside from economic and other considerations). Attaining the threshold level would require government and private investments in infrastructure in the order of tens of billions of dollars in a very short time. It would also exclude the possibility of having more than one or two competitive different fuels at one time. The infrastructure required would vary considerably from fuel to fuel. The implications are explored for each fuel below.

- **Ethanol and methanol —** a large proportion of the existing equipment could be easily adapted as these two fuels have obvious physical similarities to gasoline, i.e., use same pumps and dispensing equipment. However in the case of methanol, its corrosive nature would demand upgrading the system's reservoirs and pipes. There are additional expenses associated with differences in water tolerance and fuel contamination, fire, and explosion hazards.

- **CNG and LPG —** there is a small infrastructure capable of handling vehicle fleets successfully. Both fuels are, and will continue to be, attractive for the vehicle fleet subset, because a central refueling site can service the entire fleet. However, for private passenger cars, adapting a single existing gasoline service station would require a minimum of $250,000 for a compressor. Such a price tag would rule out a wide distribution network for passenger vehicles unless there is some government subsidy.

- **Electricity —** the extensive existing electricity infrastructure should be capable of servicing a large number of vehicles in terms of megawatts of off-peak capacity. On-peak demand would cause massive cost and availability problems. Moreover, since long refueling time would make service station refueling impossible, costly adapters would have to find a place in every user's household.

- **Hydrogen —** although there is an almost limitless supply of raw materials (e.g., water), there is no existing infrastructure for the distribution of hydrogen. Hydrogen's low mass makes it expensive to store since it must be liquified or bound to other substances. For these reasons reaching the necessary threshold level would involve a much higher price tag than for other ATFs.

EXPONENTIAL RATE OF CLOSURE

The growth factors described above were used to determine the exponential rate of closure in the availability gap between gasoline and each ATF, for each penetration scenario. Assumptions and caveats in addition to the ones outlined above are provided after the table.

Table E-34. Availability Gap Closure Rates, By Scenario

FUEL TYPE	PENETRATION SCENARIO		
	BASE	HIGH	LOW
Diesel	99%	99%	99%
Ethanol	10%	20%	2%
Methanol	10%	20%	2%
CNG	10%	20%	2%
LPG	10%	20%	2%
Electricity	10%	40%	2%
Hydrogen	10%	10%	2%

ASSUMPTIONS AND CAVEATS

- Accelerated exponential rates in all penetration cases, especially in the high case, such that a common market would appear in the United States within ten to twenty years. The market arrival time span for each fuel was calculated based on each fuel individually without any other ATF challenger. Such a individual competition approach is inconsistent with the model specifications.

- Regional differences in availability are highly unlikely in any national market, though they can exist initially.

- Even though regional fuel price differences may persist due to transportation costs from producing or importing regions, availability differences cannot, and will not persist if a national market develops.

- It is not clear what constitutes availability for EV's, i.e., whether refueling time refers to recharging batteries as opposed to switching them. Therefore arbitrary assumptions have been made for this category.

SPECIFIC REFERENCES AND SOURCES

- **Gasoline —** Reformulated gasoline may require $20 to $40 billion in upgraded refineries (Woodruff, 1991, p.56).

- **Methanol —** Cannot be integrated into current distribution system without modifying the system: water tolerance and fuel contamination, materials compatibility in storage and distribution systems, fire and explosion hazards (A.P.I., September 1990, p.27).

- **CNG —** High pressure compressors cost $250,000 each (Woodruff, 1991, p.57).

- **LPG —** There are 10,000 propane refueling stations in the United States (Frank, 1992, p.106).

- **Hydrogen —** Supply of Hydrogen (Frank, August 1992, p.106).

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Attachment 3: LDV Stock Module

Fuel Economy Gap Estimation

INTRODUCTION

This attachment presents long-term projections of the fuel efficiency degradation factor for automobiles and light-duty trucks. The projections are based on the analysis of important trends in driving patterns that affect fuel economy. These trends include the increase in urban share driving, urban congestion, and highway speeds. The projections are developed for the period 1990 through 2020. This appendix also outlines other efforts to project fuel economy degradation factors.[30]

BACKGROUND

A discrepancy exists between automotive fuel economy as measured by the Environmental Protection Agency (EPA) under controlled laboratory conditions and the actual fuel efficiency observed under real "on road" conditions. Public and private organizations such as the Department of Energy (DOE), the Environmental Protection Agency (EPA), Ford Motor Company, General Motors Corporation, and Mitsubitshi Motors Corporation have conducted independent research on fuel economy, in the past, confirming this discrepancy.[31] The fuel efficiency degradation factor (also known as "the gap") measures this discrepancy and is defined as the difference between on-road fuel economy and EPA tested fuel economy.[32] When fuel economy is expressed in terms of miles per gallons (MPG), the degradation factor or gap is formulated as:

$$GAP = \frac{EPA\ TEST\ MPG - ON\text{-}ROAD\ MPG}{EPA\ TEST\ MPG}$$

[30] This appendix is taken from a report which was prepared by Decision Analysis Corporation of Virginia (DAC) for the Energy Demand Analysis Branch of the Energy Information Administration (EIA), under Task No. 92010, Subtask 1, Contract No. DE-AC01-92EI21946.

[31] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), p.3-9,March 1992.

[32] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

On-road fuel efficiency depends on several determinants which can be classified into technological factors, driver behavior and habits, driving trends, and road and climate conditions. Furthermore, the magnitude of the gap between tested fuel efficiency and on-road fuel efficiency depends on the specific procedures and conditions used during the test and the closeness of the formulations used to represent real driving conditions.

EPA fuel economy estimates for city and highway driving are published every year for each new model available in the U.S.[33] These MPG estimates are obtained based on vehicle tests performed under controlled laboratory conditions and then adjusted downwards to reflect actual driving conditions. Separate tests are used to generate the city and highway MPG estimates.

The EPA city fuel economy estimates are based on a test that simulates a 7.5 mile, stop-and-go trip with an average speed of 20 mph. The trip lasts 23 minutes and has 18 stops. About 18 percent of the time is spent idling, such as waiting for traffic lights or in rush hour traffic. Two types of engine starts are used: a cold start and a hot start. The cold start is similar to starting the car in the morning after it has been parked all night. The hot start is similar to restarting a vehicle after it has been warmed up, driven and stopped for a short time.

The EPA highway fuel economy estimates represent a mixture of "non-city" driving. Segments corresponding to different kinds of rural roads and interstate highways are included. The test simulates a 10-mile trip and averages 48 mph. The test is run from hot start and has little idling time and no stops.

EPA adjusts these laboratory fuel economy estimates downwards to reflect actual driving on the road conditions. In the 1992 Gas Mileage Guide: EPA Fuel Economy Estimates the city estimates are lowered by 10 percent and the highway estimates by 22 percent from the laboratory test results. These adjustment factors represent the EPA estimates of the fuel efficiency gap for both city and highway driving.

Fuel economy can also be represented by a composite number that combines city and highway fuel economies. EPA computes composite fuel economies using the following formulation:

$$EPA\ COMPOSITE\ MPG = \left[\frac{0.55}{MPG_c} + \frac{0.45}{MPG_h}\right]^{-1}$$

[33] DOE/EPA, Gas Mileage Guide: EPA Fuel Economy Estimates, DOE/CE-0019/10.

where:

MPG_c = Miles per gallon for city driving
MPG_h = Miles per gallon for highway driving

EPA's composite formulation is developed based on 55% city driving and 45% highway driving. This formulation, combined with the EPA city and highway fuel efficiency gaps, leads to a base composite MPG gap for all new vehicles of 15 percent.

Previous attempts at estimating the base fuel efficiency gap have been made. In 1978, McNutt et al., measured the gap for model year 1974 through model year 1977 cars. The resulting estimates of the gap were between 6 and 9 percent.[34] In 1984, Hellman and Murrel estimated a composite MPG gap of 15 percent.[35] More recently in 1992, Oak Ridge National Laboratory (ORNL) reported composite gap estimates that apply to all automobiles and light trucks in operation.[36] The ORNL base composite gap estimate for all automobiles in operation pre-1974 to 1989 was 15.2 percent. The ORNL gap estimate for light trucks in operation pre-1976 to 1989 was 28.3 percent. For this analysis, ORNL used EPA tested fuel economy data which was verified by the National Highway Safety Administration (NHTSA). These data were compared against on-road fuel economy data from (1) the Federal Highway Administration (FHWA) Highway Statistics 1989, (2) the Department of Energy, Energy Information Administration, 1988 Residential Transportation Energy Consumption Survey (RTECS), and (3) the Bureau of the Census, 1987 Census of Transportation, Truck Inventory and Use Survey (TIUS).

Very few attempts to forecast trends in the fuel economy gap are available. In 1989, Westbrook and Patterson analyzed trends in driving patterns and produced forecasts of the fuel economy gap for the year 2010.[37] Their results indicated a composite gap of 29.7 percent for automobiles for the year 2010. This combined fuel efficient gap corresponded to a city fuel efficiency gap of 23.5 percent and a highway fuel efficiency gap of 30.5 percent. Organizations such as Data Resources Incorporated (DRI) and Wharton Econometrics Forecasting Associates (WEFA) use values for the degradation factors that remain constant over their forecasting horizon. The Department of Energy (DOE) and

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[34] SAE 780037

[35] SAE 840496

[36] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), p.3-9,March 1992.

Maples, John D., and Philip D. Patterson, "The Fuel Economy Gap for All Automobiles and Light Trucks in Operation," Draft, Washington, DC,1991.

[37] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

the Energy Information Administration (EIA) in the 1990 National Energy Strategy (NES) projected the fuel efficiency gap to reach 30 percent by 2030 in the NES reference case.[38] The projected gap for the High Conservation and the Very High Conservation cases of NES were 25 and 20 percent respectively. Also, EIA in the Annual Energy Outlook 1992 (AEO) projected the fuel efficiency gap to increase from 20 percent in 1990 to 25 percent in 2010.

An ongoing effort by DOE's Office of Transportation Technologies in conjunction with the University of Tennessee is focused on forecasting the fuel efficiency gap for automobiles and light duty trucks through 2010. This work considers three scenarios based on differing assumptions about urban shares, highway speed, and congestion trends.

This attachment presents independent projections of the fuel efficiency gap to the year 2020 for two vehicle types:

1) Automobiles, and
2) Light Duty Trucks

The projections are generated based on the analysis of three important trends in driving patterns that affect fuel efficiency. These factors are:

1) increasing urban share of vehicle miles traveled,
2) increasing average highway speed, and
3) increasing level of urban highway congestion.

Logistic Approach

The historical urban share of automobile VMT driving from 1972 through 1997 was estimated with a logistic curve fitted to the historical period and extended through the year 2020. The logistic share values are developed based on a logistic functional form originally formulated by Fisher and Pry[39] and defined by:

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[38] EIA, Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy, SR/NES/90-02, Service Report, p. 89, Washington, D.C., December 1990.

[39] Fisher, J.G. and Pry, R.M., "A Simple Substitution Model of Technology Change." Technological Forecasting and Social Change, Vol.3, pp.75-88, 1971.

$$F_t^U = \frac{F_\infty^U}{1 + E^{-(\alpha+\beta t)}}$$

where:

F_t^U	is the urban share in year t,
F_∞^U	is the urban share asymptotic limit, α and β are parameters of the logistic curve defined by:

$$\alpha = LN[F_0^U / (F_\infty^U - F_0^U)],$$

$$\beta = (1/H^U) LN[(F_\infty^U + F_0^U) / F_0^U],$$

where:

F_0^U	is the base year urban share, and
h^U	is the halving factor for the logistic curve. The halving factor is the time required from the base year for the urban share to reach the midpoint between its base year value and its asymptotic limit.

The logistic curve represents the curve that best fits the historical data on urban share for the 1972-1997 period. This curve is generated by assuming two logistic parameters and by selecting a base share year. These two parameters are the asymptotic limit and the halving factor. The asymptotic limit represents an upper limit to the growth of the urban share. The halving factor is a measurement of the time needed for the share to reach this upper limit. The values for both parameters are specific to the best fit curve and they are determined using an iterative approach which minimizes the sum of the squares of the difference between the historical shares and the logistic estimated shares.

Procedure

Projections were generated for each of the vehicle types, and factors. First it is assumed that all urban driving is city driving and all rural driving is highway driving. Fuel economy gap projections generated in the past are based on such an assumption, as it makes the gap calculations considerably easier. However, the assumption oversimplifies reality since some of the urban driving is on interstate highways and other freeways located in urban areas, and some of the rural driving includes stop-and-go city type of driving. The second set of projections were generated taking into consideration the decomposition of urban and rural driving into city and highway driving according to road types. This adjusted city/highway driving share approach was deemed more realistic. This is due to the fact that such an approach more closely resembles actual driving behaviour and consequently avoids the restricting assumption that urban driving is equal to city driving and rural driving is equal to highway driving. As such, only these calculations are included in this attachment.

The decomposition is based on road types. Thus, VMT driving on roads identified as "interstate" and "other freeways and expressways" in urban areas are considered part of the highway driving share. Other road types located in urban areas are considered part of the city driving share. In addition, VMT driving on roads defined as "minor collectors" and "local" in rural areas are classified as city driving while the rest of the road types in rural area are considered highway driving. Although this road classification does not exactly replicate reality, it is a closer representation of the actual city/highway driving composition.

Approximately 63 percent of total 1990 VMT consisted of driving in urban areas and 37 percent in rural areas. 68 percent of the urban VMT is considered city driving and 32 percent highway driving. In rural areas, 17 percent is considered city driving and 83 percent highway driving. This composition represents overall city and highway driving shares for 1990 of:

City Share:	49.1 %
Highway Share:	50.9 %

These adjusted city and highway shares are the bases for the calculations of the fuel efficiency gap projections in this chapter. The impact on fuel efficiency, from each of the three factors considered in this study, is affected by these adjusted shares. The impact from the increasing urban share trend is diminished since only part of the urban share (68% in 1990) is considered city share. The impact from increasing highway speeds is amplified since highway driving in both urban and rural areas is considered. Finally, the impact from increasing urban highway congestion is diminished since only part of the urban share is considered highway driving. The resulting fuel efficiency gap projections for automobiles and light duty trucks using the logistic approach based on these adjusted shares will be presented.

FUEL EFFICIENCY GAP PROJECTIONS

This section outlines the three trends which are assumed to affect the fuel efficiency gap estimates of the EPA. It then presents the projections of the fuel efficiency gap which have been utilized in the NEMS Transportation Sector Model.

Increasing Urban Share Driving

A review of the data from the last few decades on VMT for both automobiles and light duty trucks reflects a continuous increase in the share of urban driving.[40] For automobiles the urban share increased from 45.4 percent in 1953 to 62.9 in 1990. The historical urban share of VMT for automobileshas increased by 38.5 percent in 37 years, or an average annual rate of increase of 0.88 percent. For light duty trucks the urban share increased from 39.5 percent in 1966 to 55.4 in 1990. The historical urban share of VMT for light duty trucks has similarly increased by about 40.3 percent in 24 years, or an average annual rate of increase of 1.42 percent.

Westbrook and Patterson investigated the reasons for this increase in urban share by analyzing the data for the period from 1975 through 1985.[41] Their results indicated that the major reasons for this increase are the larger fraction of travel in urban roads and a larger fraction of roads being classified as urban. Population shifts to urban areas and driving shifts within metropolitan areas account for the larger fraction in urban driving which was estimated to be the cause for 58 percent of the increase in urban share. The other 42 percent increase was determined to be the consequence of the reclassification of roads from rural to urban. Any area reclassified by the U.S. Bureau of the Census from rural to urban results in the reclassification of all roads (regardless of the type) as urban.

The urban/rural split represents the share of cars and trucks that are divided between urban driving and rural driving. The EPA's calculation for composite fuel economy assumes that 55 percent of driving takes place in the city and 45 percent is on the highway. Urban driving has increased from almost 50 percent in 1980 to over 62 percent of total driving by 1995. The composition of urban driving has changed as a further disaggregation of the urban/rural split into local and highway categories will indicate. The Census Bureau's reclassification of areas from rural to urban has

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[40] Data on VMT is published annually by the U.S. Department of Transportation, Federal Highway Administration, in Highway Statistics.

[41] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

contributed to the amount of driving in the city share to rise dramatically.[42] A significant portion of the increase in urban driving has occurred among the urban highways. Adjustments therefore must be made to the urban share that contributes to fuel degradation, because urban highway speeds are higher than typical local urban speeds. Urban sprawl is another factor contributing to the increasing shares of urban versus rural driving as cities expand into the suburbs. The urban/rural split in combination with analyzing which vehicle type is experiencing an increase in vehicle miles traveled (VMT) will permit more precise evaluation as to the causing leading to increasing degradation over time. [43] The difference between changes in the vehicle stock composition by vehicle type over time is important when assessing fuel degradation because light duty trucks tend to get less miles per gallon than automobiles, and their fuel efficiencies vary with their usage patterns.

Forecasts of the shares of urban and highway driving are necessary in order to forecast the change in the fuel efficiency gap due to changes in driving shares. It is very difficult to draw conclusions about the increasing trend in urban driving. Nevertheless, it can be expected that population shifts to urban areas will continue and that future land developments will force the reclassification of rural areas into urban areas. If we assume that this rate of increase in urban share will gradually diminish and level off, the logistic path applies.

The proportion of urban and rural highway vehicle miles traveled for both automobiles and light trucks are forecasted by using Federal Highway Administration (FHWA) VMT data. Listed below are three estimations: highway share of automobile urban travel, highway share of automobile rural travel, and total urban share of automobile travel. All of the regressions use time as the independent variable, with the exception of highway share of automobile rural travel; the rural automobile estimation includes gasoline prices and income.

$$Share_{Year} = Share_{1980} + (Share_{Max} - Share_{1980}) * [\, 1 - e^{(k_1 (Year - 1980) + k_2 (Y) + k_3 (GP)} \,]$$

Where: Y = income and GP = gasoline price.

Personal disposable income is another factor that may contribute to fuel degradation. Historically,

[42] Meyer, John. *NEMS Transportation Sector Model: Re-estimation of Fuel Economy Degradation Factors.* Prepared for Energy Information Administration by Decision Analysis Corporation of Virginia. Subtask 23; December 1997.

[43] Federal Highway Administration, *Highway Statistics*, 1997 and prior issues, FHWA Table VM-1,VM-2.

as personal disposable income increases, consumers spend more money on their vehicles.[44] In combination with urban sprawl as consumers move to a more rural area and commute further to work, rising incomes potentially lead to cars or trucks that are more expensive and have lower fuel economy. With greater income consumers can also afford to pay more for gasoline than when their income was smaller which may lead to more gasoline consumption and higher VMT in rural areas.

	AUTOMOBILES
Urban	Regression
Constant	0
Std Err of Y Est	0.0747
R Squared	0.9543
No. of Freedom	18
Degrees of	17
X Coefficient(s)	-0.0632
Std Err of Coef.	0.0018
T-Stat	-35.7121

	AUTOMOBILES		
Rural	Regression Output:		
Constant			0
Std Err of Y Est			0.1313
R Squared			0.7933
No. of Observations			18
Degrees of Freedom			15
	Income	Time	Gas
X Coefficient(s)	0.0001	-0.0933	-0.0064
Std Err of Coef.	0.0000	0.0142	0.0015
T-Stat	4.7765	-6.5908	-4.1883

	AUTOMOBILE		
Urban	Regression		
Constant			0
Std Err of Y Est			0.0899
R Squared			0.6885
No. of Observations			18
Degrees of Freedom			17
X Coefficient(s)		-0.0271	
Std Err of Coef.		0.0021	
T-Stat		-12.7218	

[44] Disposable Personal Income Per capita chained 1992 dollars. Provided by Department of Commerce Bureau of Economic Analysis and Bureau of the Census for the Economic Report of the President. Washington, DC. 1997.

Once the total share of urban automobile travel is forecast, the remaining portion corresponds to rural automobile travel. Within each, urban and rural, the proportion represented by highway versus local travel is determined by the corresponding highway shares equations. After each are forecasted, these highway and local shares within both urban and rural will be used to weight the fuel economies associated with category.

TRUCKS

Urban	Regression Output:	
Constant		0
Std Err of Y		0.0491
R Squared		0.9881
No. of Observations		18
Degrees of		17
X	-0.0804	
Std Err of	0.0012	
T Stat	-69.1119	

Rural Trucks	Regression Output:	
Constant		0
Std Err of Y Est		0.1139
R Squared		0.9470
No. of		18
Degrees of		17
X Coefficient(s)	-0.0828	
Std Err of Coef.	0.0027	
T stat	-30.7225	

Total

Urban Trucks	Regression Output:	
Constant		0
Std Err of Y Est		0.1139
R Squared		0.9016
No. of		18
Degrees of		17
X Coefficient(s)	-0.1237	
Std Err of Coef.	0.0054	
	-23.03	

Increasing Highway Speeds

The level of speed of a vehicle is one of the relevant factors that affects its fuel efficiency. Specifically, it has been determined that speeds over 45 mph decrease fuel efficiency for most vehicles. Furthermore, EPA estimates that traveling at 65 mph as compared to 55 mph lowers fuel economy over 15 percent.[45] ORNL's 1992 Transportation Energy Data Book presents the findings of a fuel economy study performed by the Federal Highway Administration in 1984.[46] This study concluded that, on average, vehicles experience fuel efficiency losses of about 17.8 percent when their speed is increased from 55 mph to 65 mph. This is equivalent to a reduction of 1.78 percent for each mile per hour increase over speed ranging from 55 mph to 65 mph.

Average highway speeds in the United States have shown an increasing trend for several years with few exceptions. Historical data indicates two different increasing trend periods. The first period from 1945 through 1973 corresponds to the largest rate of increase on highway speeds. During these years, highway speed increased at an annual rate of 1.13 percent. In 1973, average highway speed suddenly dropped from about 66 mph to about 55 mph. This sudden drop corresponds to the implementation of the nationwide 55 mph speed limit. After 1974, the increasing trend has continued at a more moderate rate. In the 1974-1990 period the annual rate of speed increase has been 0.15 percent. A closer look at the post-1973 period indicates that through the rest of the 1970s, the average speed remained fairly constant between 55 and 56 mph; and, through the 1980s, the annual rate of increase was 0.34 percent.

The increase in highway speed can also be illustrated by considering the percentage of rural and urban VMT driving over 55 mph on highways with posted speed limits of 55 mph. In only 9 years from 1981-1990, the percent of rural VMT driving over the 55 mph speed limit rose from 46.4 percent to 58.7 percent for a total of 12.3 percentage points. The percentage increase in urban VMT driving was even more dramatic, from 37.6 percent to 53.8 percent for a total of 16.2 percentage points. The percentage exceeding the speed limit is far from homogeneous. Significant differences exist across states, highway types, and location for rural or urban areas. For instance, in 1990 the percentage of vehicles exceeding the 55 mph limit in urban interstate highways in New York was 82.5 as compared to 68.2 in California and only 33.7 in South Dakota.

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[45] DOE/EPA, 1992 Gas Milage: EPA Fuel Economy Estimates, DOE/CE-019/10, October 1991.

[46] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), Table 3.42, p.3-66,March 1992. 1984 data from U.S. Department of Transportation, Federal Highway Administration, Fuel Consumption and Emission Values for Traffic Models, Washington, D.C., May 1985.

The estimation of the overall impact of speed trends in fuel economy is dependent on the specific data type selected to measure this trend and on the methodology used to forecast this trend. One could choose a disaggregated approach in which speed trend forecasts are developed by urban and rural driving, highway type, and vehicle type, for each state. Given the time limitations, the current study utilizes the nationwide average highway speed for all vehicles and highway types. Average speeds post-1980 are used as the basis to generate forecasts.

Average highway speed is influenced by regulatory policies such as the implementation of the nationwide speed limit in 1973-1974. Other factors affecting speed might include safety and environmental regulations, gasoline prices, oil shortages, income fluctuations, etc. Although a methodology to forecast speed trends which includes all relevant factors is desirable, a logistic approach based on historical trends has been applied.

With the recent posted increases in the speed limit since 1995, there has been a rise in average highway speed and an increase in the fuel degradation factor.[47] In 1995 the National Highway System Designation Act (NHSD) was signed into law, which eliminated the Federal mandate for the National Maximum Speed Limit (NMSL).[48] NHSD stems from a series of other acts that deal with either raising or lowering highway speeds. In 1973, the National Maximum Speed Limit Act (NMSL) set the maximum highway speed at 55 miles per hour. This was imposed during the Arab oil embargo in the 1970's with the intent to conserve fuel. In 1987, the Surface Transportation and Uniform Relocation Assistance Act allowed states to raise the speed limit on portions of the rural Interstate system and some other "experimental" roads as long as they did not exceed 65 mph.[49] With the drop in fuel prices over the years, the public has tried to eliminate the NMSL on the grounds that it is not as important to have federal laws regulating speeds in order to conserve fuel.

Fuel economy rises with increasing speed until approximately 40 miles per hour (mph). Further increases in vehicle speed lead to a reduction in fuel economy. Therefore, it is possible to estimate the loss in fuel economy by the increase in average highway speeds. Unfortunately, federal average highway speed data is only available through the year 1993 because of cuts in funding for the

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[47] Greene, Michael A; Retting, Richard A. *Traffic Speeds Following Repeal of the National Maximum Speed Limit.* ITE Journal, May 1997, pp. 42-46.

[48, 49] *The Effects of Increased Speed Limits in the Post-NMSL Era. Report to Congress from the National Highway Traffic Safety Administration. Washington, DC. February 1998.*

collection of this data.[50] There is some data from individual states which confirms that highway speeds are increasing at the state level, but no data is available on the national level.[51]

The highway MPG for urban and rural is adjusted by the speed factor. The forecast data for average highway speeds begins after 1993. The forecast data is different for urban and rural reflecting the fact that speed limits are higher in rural areas. Thus, the degradation factor applied to rural roadways is higher than the factor applied to urban roadways. The speed data is forecast to an assumed asymptotic maximum as described in the function below. This assumes that highway speeds will continue to increase in the future up to a maximum of 70 mph.

$$MPH_{year} = MPH_{1980} + (MPH_{max} - MPH_{1980}) * [1 - e^{k1(Year - 1980)}]$$

The EPA standard degradation factors of 10 and 22 percent for autos and light trucks are also applied. Once all these factors are applied, we obtain an estimate of revised fuel economy for automobiles and light trucks. Given how fuel economy varies by speed, the increasing forecasted speeds are used to predict the percentage decline in fuel efficiency over time. The speed factors are then applied to the highway fuel efficiency numbers for both urban and rural.

Increasing Urban Highway Congestion

Congestion is a primary issue of the domestic transportation system. Urban congestion has increased in the last decades in most metropolitan areas as expansion and improvement of the transportation system lagged behind the rapid growth of travel demand.

The Federal Highway Administration (FHWA) classifies the two major causes of urban road congestion as recurring congestion and non-recurring congestion. Recurring congestion is that congestion which is the consequence of inadequate road capacity, reduction of through-put lanes, narrowing of lane widths, physical barriers, inadequate traffic light synchronization, and other

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[50] Davis, Stacy C. Transportation Energy Data Book. U.S. Department of Energy, Oak Ridge National Laboratory. ORNL 16; Table 3.48 and ORNL 17; Table 3.45

[51] Klausmeier, Rob; Kozak, Robert. *Emissions and Fuel Consumption Effects of Speed Limit Increases Legislated By The NHSDA of 1995.* Prepared for Energy Information Administration, Department of Energy. November 1997.

similar causes. FHWA estimates that recurrent congestion accounts for 40 percent of all urban road congestion. Non-recurring congestion is that congestion resulting from disabled vehicles and accidents. FHWA estimates that disablement account for 55 percent of overall urban congestion, with the remaining 5 percent due to accidents.

One of the most important road types within urban areas in which congestion takes place is urban freeways. In 1990, 32 percent of the total vehicle miles of travel in urban areas corresponded to freeways, while freeways comprised only 5.7 percent of the urban roadway mileage.[52] The increase in urban congestion can be further analyzed by considering the increase in urban VMT as compared to the increase in urban lane miles. Data corresponding to the period 1975-1987 indicate that urban VMT demand growth rate is over 4 times the rate of new urban lane capacity growth. This corresponds to an increase in the average urban through-put (urban VMT per mile) of 38.9 percent.

Differing methodologies have been developed recently to measure the extent and duration of freeway congestion in urban areas.[53] [54] Hanks and Lomax of the Texas Transportation Institute (TTI) have developed congestion indices for 39 urban areas. Table E-39 lists VMT, VMT per lane-mile, congestion indices, and rankings for each of the urban areas analyzed by TTI. Table E-40 lists, in addition to the congestion indices, estimates of the congestion cost per capita for each of these urban areas. Few attempts to forecast urban congestion and its effect on fuel economy are available. [55]

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[52] U.S. DOT, FHA, Highway Statistics 1990.

[53] Cottrell, P., "Measurement of the Extent and Duration of Freeway Congestion in Urbanized Areas,"ITE 61st Annual Meeting, Milwaukee, Wisconsin, Sept. 1991.

[54] Hanks, J., and Lomax, T., Roadway Congestion in Major Urban Areas: 1982 to 1987, Texas Transportation Institute, Research Report 1131-2, College Station, Texas, Oct. 1989.

[55] Lindley, J., "Urban Freeway Congestion Problems and Solutions: An Update," ITE Journal, Dec. 1989, pp. 21-23. Feng, An, "Automobile Fuel Economy and Traffic Congestion," Dissertation for PhD in Applied Physics, University of Michigan, 1992. Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

Table E-35. Congestion Index Value for Selected Cities

Urban Area	Freeway/Expressway Streets DVMT[1]	Freeway/Expressway Streets DVMT[2]	Principal Arterial DVMT[1]	Principal Arterial DVMT[2]	Congestion[3] Index	Rank
Western & Southern Cities	4,580	295	16,475	2610	1.23	4
Phoenix AZ	96,890	4,880	73,810	11,780	1.47	1
Los Angeles CA	8,055	660	6,135	1,000	1.00	17
Sacramento CA	23,155	1,640	8,180	1,560	1.08	12
San Diego CA	39,580	2,305	12,670	2,005	1.31	2
Denver CO	9,550	830	10,600	1,930	0.95	22
Miami FL	7,420	555	13,000	2,000	1.14	7
Tampa FL	3,300	280	3,880	610	1.02	16
Atlanta GA	23,940	1,600	9,350	1,500	1.16	6
Indianapolis IN	7,640	710	4,100	835	0.85	32
Louisville KY	5,380	515	2,975	520	0.86	30
Kansas City MO	11,920	1,410	4,350	910	0.69	39
St. Louis MO	16,290	1,430	11,215	1,745	0.96	20
Albuquerque NM	2,025	200	3,550	650	0.91	26
Oklahoma City OK	6,330	700	3,465	655	0.76	36
Portland OR	6,700	540	3,200	525	1.00	17
Memphis TN	3,730	375	3,930	760	0.84	34
Nashville TN	5,000	430	4,915	905	0.95	22
Salt Lake City UT	3,810	410	1,865	340	0.78	35
Seattle-Everett WA	16,600	1,140	8,950	1,475	1.14	7
Northeast & Midwest Cities						
Washington DC	22,910	1,555	18,400	2,240	1.25	3
Chicago IL	30,945	2,260	24,965	3,870	1.11	9
Baltimore MD	13,735	1,200	9,020	1,680	0.92	25
Boston MA	20,205	1,490	13,700	2,675	1.04	14
Detroit MI	21,800	1,610	21,545	3,450	1.10	11
Minn-St. Paul MN	15,620	1,230	5,200	1,160	0.97	19
New York NY	73,615	5,385	46,490	6,930	1.11	9
Cincinnati OH	9,560	845	3,315	790	0.87	29
Cleveland OH	11,185	960	4,840	1,100	0.89	27
Philadelphia PA	15,125	1,370	22,550	3,150	1.06	13
Pittsburgh PA	7,190	925	9,905	1,510	0.85	32
Milwaukee WI	6,820	570	4,640	930	0.94	24
Major Texas Cities						
Austin TX	5,150	420	2,150	415	0.96	20
Corpus Christi TX	1,500	180	1,490	320	0.72	37
Dallas TX	22,100	1,640	8,200	1,690	1.03	15
El Paso TX	3,200	345	3,000	805	0.72	37
Fort Worth TX	11,000	990	4,250	840	0.88	28
Houston TX	25,800	1,640	10,500	1,970	1.19	5
San Antonio TX	8,800	810	4,800	1,050	0.86	30
West/South Avg	15,095	1,045	9,750	1,715	1.01	
North/Midwest Avg	20,725	1,615	15,380	2,455	1.01	
Outside TX Avg	17,205	1,260	11,860	1,995	1.01	
Texas Avg	11,080	860	4,910	1,015	0.91	
Congested TX Avg	14,570	1,100	5,980	1,195	0.98	
Total Avg	16,105	1,190	10,610	1,820	0.99	
Maximum Value	96,890	5,385	73,810	11,780	1.47	
Minimum Value	1,500	180	1,490	320	0.69	

Note: Congested Texas cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio.

[1]Daily vehicle-miles of travel

[2]Daily vehicle-miles of travel per lane-mile

[3]See Equation s-1

Table E-36. 1987 Urban Area Rankings by Congestion Index and Cost per Capita

Urban Area	Congestion Index		Congestion Cost per Capita	
	Value	Rank	Value (Dollars)	Rank
Western & Southern Cities				
Phoenix AZ	1.23	4	510	10
Los Angeles CA	1.47	1	730	2
Sacramento CA	1.00	17	360	19
San Diego CA	1.08	12	280	25
San Fran-Oakland CA	1.31	2	670	3
Denver CO	0.95	22	420	14
Miami FL	1.14	7	670	4
Tampa FL	1.02	16	340	22
Atlanta GA	1.16	6	650	5
Indianapolis IN	0.85	32	100	38
Louisville KY	0.86	29	180	31
Kansas City MO	0.69	39	130	35
St. Louis MO	0.96	20	380	17
Albuquerque NM	0.91	26	250	27
Oklahoma City OK	0.76	36	170	34
Portland OR	1.00	18	300	24
Memphis TN	0.84	34	210	29
Nashville TN	0.95	23	380	18
Salt Lake City UT	0.78	35	120	36
Seattle-Everett WA	1.14	8	580	6
Northeast & Midwest Cities				
Washington DC	1.25	3	740	1
Chicago IL	1.11	9	340	21
Baltimore MD	0.92	25	340	23
Boston MA	1.04	14	400	16
Detroit MI	1.10	11	480	11
Minn-St. Paul MN	0.97	19	240	28
New York NY	1.11	9	430	12
Cincinnati OH	0.87	29	180	32
Cleveland OH	0.89	27	170	33
Philadelphia PA	1.06	13	520	9
Pittsburgh PA	0.85	32	410	15
Milwaukee WI	0.94	24	190	30
Major Texas Cities				
Austin TX	0.96	21	420	13
Corpus Christi TX	0.72	37	80	39
Dallas TX	1.03	15	530	8
El Paso TX	0.72	37	110	37
Fort Worth TX	0.88	27	360	20
Houston TX	1.19	5	550	7
San Antonio TX	0.86	30	260	26

Source: Hanks, J., and Lomax, T., Roadway Congestion in Major Urban Areas: 1982 to 1987, TTI, Research Report 1131-2, College Station, TX, Oct. 1989.

Lindley's projections of consumption statistics for the year 2005 take into account factors including time delays, wasted fuel, and user cost. The urban freeway congestion statistic projections developed by Lindley are presented in Table E-41.

The projections generated in this study utilize the wasted fuel values developed by Lindley as the basis to measure the impact of urban congestion on the fuel efficiency gap. The study further assumes that the amount of wasted fuel due to congestion will increase following a logistic trend.

The amount of wasted fuel is divided between automobiles and light duty trucks assuming that the light duty trucks VMT driving share will increase from 23.4 percent in 1989 to 33 percent in 2010, and will remain constant at 33 percent through 2030.

With increasingly greater numbers of people commuting from the suburbs to work in the city, congestion continues to climb and add time to the average American's everyday routine. A study on congestion by Texas Technology Institute indicates that congestion is on the rise in almost every metropolitan area in the United States.[56] Increasing congestion results in vehicles with their engines idling for a longer period of time. It also leads to more stop and start traffic. Both of these factors increase not only the amount of fuel consumed but also the amount of criteria pollutants emitted into the air.

The percent of congestion can be measured in terms of the volume to surface-flow (VSF) ratio.[57] The surface to flow data measures the available highway surface to the portion of the congested highway surface over a wide variety of road types, from minor arterial to freeway and interstate. The method of collection of this data has changed several times since 1980, when the data was initially collected. The most noticeable effects of these changes are in the time period 1995-1997 where the data shows a significant drop in congestion. However, the study from the Texas Technical Institute disputes this data and has found an overall increase in traffic nationwide.[58] A moving average was taken to smooth the data for more consistency in the overall growth in congestion over time.

The estimated urban and rural highway shares which were calculated in the above equations need

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[57] Federal Highway Administration, *Highway Statistics*, 1997 and prior issues, FHWA Table HM-61.

[58] Hanks, J., and Lomax, T., *"Urban Roadway Congestion."* Texas Transportation Institute, College Station, TX, Annual Report 1998.

to be adjusted by a congestion factor. The vehicle surface to flow ratio (VSF) is used to adjust the highway shares. It is assumed that when the VSF is greater than .71, roadways have 71% or greater congestion level. The congestion factor is then projected to an asymptotic maximum to predict future congestion. This assumes that congestion will continue on an upward trend and impact fuel degradation in the future.

Overall Degradation Factor Forecast

The EPA standard degradation factors as well as AEO 99 factors are used in estimating the degradation factors. After applying each factor to the fuel degradation equation an estimated fuel degradation factor is derived that allows analysis of the total impact on fuel economy. Over the forecast period, there is a steady increase in fuel consumption and depletion. By 2020 it is expected that the average automobile will have 81% degradation while the average light duty truck will have 76.5% degradation. Trucks tend to have a higher degradation than cars which may be due not only to higher speeds in rural areas, since the share of trucks is higher in rural areas than in urban areas, but also because they have lower fuel economies.

Autos will see increasing degradation if congestion continues, incomes increase, and fuel prices decrease or stay steady. Also, there already appears to be a recent trend where consumers with higher incomes are switching to sport utility vehicles that are less fuel efficient than automobiles. This switch will continue to contribute to fuel economy degradation because sport utility vehicles have a higher degradation factor than automobiles. Though income and fuel price data was only applied to rural automobiles, it may be interesting to explore its impact in other areas in future studies. Also, because income increases over time, one would not expect consumers to substitute their more luxurious vehicles for smaller more fuel efficient vehicles.

Other Factors

Highway share of vehicles, average highway speed and congestion are the most aggregate factors impacting fuel degradation in this study. Other factors like income and gasoline prices also have a significant impact. There are more factors that impact fuel degradation that are not included in this analysis. One factor this analysis tries to account for are the differences between vehicle size and type, by analyzing automobiles and light trucks separately. Vehicle age may also be a factor. Newer vehicles may be more fuel efficient due to advances in technology or due to lack of maintenance on older vehicles. Also, older vehicles may not been used as frequently as new vehicles. Use of air conditioning may be another degradation factor as it is known to deplete fuel. Vehicle origin may be another cause of fuel. Domestic produced vehicles are different from foreign vehicles and their relative stock shares over time may vary leading to either an increase or decrease in degradation factors. The technologies and parts used in various vehicles may also vary significantly and have disproportionate impacts on fuel degradation. Vehicle nameplate may be another factor because of the variations among different manufacturers. These factors may all impact fuel degradation, though the extent of their impact is not known.

Table E-37. Urban Freeway Congestion Statistics

	1984	1987	(1984 data) 2005	(1987 data) 2005
Freeway Miles	15335	16097	15335	16097
Vehicle-Miles of Travel (billions)	277	337	411.0	493
Recurring delay (million vehicle-hours)	485	728	2049	3030
Delay due to incidents (million vehicle-hours)	767	1287	4858	7978
Total delay (million vehicle-hours)	1252	2015	6907	11008
Total wasted fuel (million gallons)	1378	2206	7317	11638
Total user costs (billion dollars)	9	16	51	88

Source: Lindley, J., "Urban Freeway Congestion Problems and Solutions: An Update," ITE Journal, December 1989, pages 21-23.

Attachment 4: Light Duty Vehicle Fleet Model

Characteristics of Fleet Vehicles

Aggregation of EPACT Requirements

Under the provisions of EPACT, purchases of vehicles by fleets meeting certain criteria are affected by the requirement that a proportion be alternatively fueled. The specific conditions under which these provisions are in effect, and the fleet sizes which are affected are not static, but are subject to revision. The impact of the current legislation on different fleet types is tabulated below.[59]

Table E38: Federal Mandates for Alternative-Fueled Vehicles

Year	Percent of Total Light Duty Vehicle Acquisitions				
	Federal	State	Fuel Providers	Electric Utilities	Municipal & Private
1996	25	10	30	–––	–––
1997	33	15	50	–––	–––
1998	50	25	70	30	–––
1999	75	50	90	50	20
2000	75	75	90	70	20
2001	75	75	90	90	20
2002	75	75	90	90	30
2003	75	75	90	90	40
2004	75	75	90	90	50
2005	75	75	90	90	60
Thereafter	75	75	90	90	70

Affected fleets are also distinguished by geographical location: fleets of 50 or more of which 20 or more are located in metropolitan areas with a population over 250,000 with the capability of central refueling.[60] Federal mandates for the three fleet types considered by the model are estimated using a stock-weighted average of the relevant categories above, and identified as $EPACT3_{ITY,T}$ in the code. Business fleets are directly mapped to the "Municipal and Private" column above, government fleets combine "Federal" and "State" requirements, and Utility fleets combine the "Fuel Providers" and "Electric Utilities" mandates. Weighting factors are derived from recent stock estimates, and are subject to periodic revision.

[59] The table has been reproduced from *Alternatives To Traditional Transportation Fuels 1994, Volume 1,* U.S. Department of Energy, Energy Information Administration, DOE/EIA-0585(94)1, February 1996, Table 1.

[60] PL 102-486 §301(5)(A)&(B), and §301(9), 10 CFR 106 STAT. 2866, et. seq.

Business Fleet Stratification for Automobiles

Vehicles which are categorized under the somewhat broad definition of business fleets include automobiles used for daily rental and long term leasing--vehicles not intended to be covered under the alternative fuel provisions of EPACT. As the AEO95 model was structured, all business fleet vehicles were considered to be covered by the legislation, resulting in an elevated estimate of the consequent sales of alternative fuel vehicles. A time series of the number of automobiles in each category is tabulated in the table below. The fraction of business fleet vehicles which would be subject to EPACT shows a distinct downward trend over the past twenty years, as depicted below, reaching approximately 50 percent in 1990.

Table E-39: Business Fleet Distribution of Vehicles

	Business Fleets			Percent Covered
	Total	Covered	Uncovered	
1971	3,900	2,336	1,564	59.90%
1972	4,107	2,449	1,658	59.63%
1973	4,430	2,691	1,739	60.74%
1974	4,482	2,740	1,742	61.13%
1975	4,553	2,763	1,790	60.69%
1976	4,858	2,911	1,947	59.92%
1977	5,075	2,952	2,123	58.17%
1978	5,411	3,003	2,408	55.50%
1979	5,554	3,054	2,500	54.99%
1980	5,692	3,139	2,553	55.15%
1981	5,679	3,163	2,516	55.70%
1982	5,567	3,125	2,442	56.13%
1983	5,641	3,182	2,459	56.41%
1984	5,972	3,216	2,756	53.85%
1985	6,184	3,276	2,908	52.98%
1986	6,438	3,163	3,275	49.13%
1987	6,606	3,298	3,308	49.92%
1988	6,869	3,414	3,455	49.70%
1989	6,978	3,413	3,565	48.91%
1990	6,974	3,455	3,519	49.54%

A new variable, BFLTFRAC, has been established to further stratify the stock of business fleet cars, with only the "covered" vehicles being used to estimate AFV purchases under EPACT. This variable is estimated using an asymptotic extrapolation of the historical trend, using an assumed lower limit of 40 percent, and a functional form as follows:

$$TFRAC_{T-1971} = BFLTFRAC_{MIN} + (BFLTFRAC_{MAX} - BFLTFRAC_{MIN}) \cdot EXP^{(K_2 \cdot (T}$$

The input assumptions, estimated coefficients, and extrapolated values of BFLTFRAC are provided below.

Covered Business Fleet Extrapolation	
Input Assumptions	
$BFLTFRAC_{MIN}$	40%
$BFLTFRAC_{MAX}$	61.2%
Base Year	1971
Regression Output	
k_2	-0.0404
R^2	0.839

Distribution of Fleet Light Trucks

As noted in the amended documentation, the Light Duty Vehicle Fleet Module first estimates the sales of light trucks to fleets as follows:

$$FLTSAL_{VT=2,ITY,T} = FLTTRAT \cdot SQDTRUCKSL_T \cdot FLTSHR_{ITY}$$

where:

FLTSAL = Sales to fleets by vehicle and fleet type
FLTTRAT = Fraction of total truck sales attributed to fleets
SQDTRUCKSL = Total light truck sales in a given year, obtained from the NEMS Macroeconomic Module
FLTSHR = Fraction of fleet trucks purchased by a given fleet type
VT = Index of vehicle type: 1 = cars, 2 = light trucks
ITY = Index of fleet type: 1 = business, 2 = government, 3 = utility

The fleet allocation factor, FLTTRAT, has been previously extracted from data provided in the Transportation Energy Data Book,[61] which provides and estimate of the fraction of light trucks sold for personal use, and a survey of fleet vehicles,[62] which provides a mechanism for further stratifying non-personal sales into fleet/non-fleet categories. Under the current revision, only the personal/non-personal distinction is used, with all non-personal sales of light trucks being allocated to the fleet module. There are two reasons to re-estimate the value of FLTTRAT rather

[61] *Transportation Energy Data Book: Edition 12,* Oak Ridge National Laboratory, ORNL-6710, March 1992, Page A-12.

[62] *Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices,* Oak Ridge National Laboratory, ORNL-6717, May 1992.

than merely redefining it as the percentage of trucks sold for non-personal use: first, the value of the personal-use sales share reported by ORNL is derived from the 1987 TIUS, which has been superseded by the recently published 1992 survey; and second, because TIUS does not survey government and publicly-owned vehicles, the sales share derived from its summary tends to overestimate the fraction of LDT's sold for personal use. A derivation of the updated value for FLTTRAT follows.

In estimating this factor, it is necessary to combine elements of two different data samples: the relevant components of TIUS, [63] and the annual data collected by FHWA.[64] Although these surveys are drawn from different populations and are not directly comparable, it is assumed that the relationships among elements of one data set are also valid in the other. Vehicle characteristics from the 1992 FHWA survey are tabulated below:

Table E-40: FHWA Highway Statistics 1992

Total Number of Trucks (All Types)	45,504,067	Table VM-1
Total Light Duty Trucks (2-Axle, 4-Tire)	39,533,142	
Total Federally-Owned Trucks	281,623	Table MV-1
Total State & Municipal Trucks	1,547,020	

1) First, the FHWA data is used to estimate the fraction of two-axle, four tire trucks in the truck population:

$$PERCENT\ LDT = \frac{TOTAL\ LDT}{TOTAL\ TRUCKS} = \frac{39{,}533{,}142}{45{,}504{,}067} = 86.88\%$$

2) Assuming that the distribution of trucks is uniform across sectors, the number of LDT's owned by federal, state, and municipal agencies can be estimated:

$$= (FEDERAL\ TRUCKS + STATE\ \&\ MUNICIPAL\ TRUCKS) \cdot PERCENT\ LL$$

[63] *1992 Census of Transportation: Truck Inventory and Use Survey*, U.S. Department of Commerce, Bureau of the Census, TC92-T-52, May 1995.

[64] *Highway Statistics 1992*, U.S. Department of Transportation, Federal Highway Administration, FHWA-PL-93-023.

3) Using the numbers above, the fraction of LDT's owned by public agencies is estimated:

$$Percent\ Public\ LDT = \frac{Public\ LDT}{Total\ LDT} = 4.02\%$$

It is assumed that this figure represents the degree of underestimation of LDT stock in the TIUS survey, which does not include publicly-owned vehicles.

4) To reconcile this discrepancy, the total number of privately-owned LDT's from the TIUS microdata file (on CD-ROM) is subsequently adjusted:

$$IMPLIED\ TIUS\ LDT\ POPULATION = \frac{TOTAL\ TIUS\ LDT}{1 - PERCENT\ PUBLIC\ LDT}$$

5) Using TIUS estimates of the number of LDT's employed for personal use, the percentage of personal-use trucks can then be calculated:

$$PERCENT\ PERSONAL\ LDT = \frac{TOTAL\ TIUS\ PERSONAL\ LDT}{IMPLIED\ TIUIUS\ LDT}$$

6) Finally, the percentage of LDT's assigned to the Fleet Module is simply calculated:

$$FLEET\ PERCENT = FLTTRAT = (1 - PERCENT\ PERSONAL\ LDT)$$

The results are tabulated below.

Table E-41: TIUS LDT Data and Distributions

Total LDT's, from TIUS	53,435,873
Implied Total LDT's	55,673,175
Total Personal-Use LDT's, from TIUS	39,766,945
Percent Personal-Use	71.43%
Percent Fleet (FLTTRAT)	28.57%

The use of this revised allocation factor will result in a more accurate distribution of light-duty trucks in both the personal-use and fleet modules.

Fleet Share Distribution

The above information, combined with vehicle-use information from TIUS can be used to re-estimate the allocation of trucks among fleet types. This parameter, FLTTSHR, allocates total fleet LDT purchases among business, government, and utility fleets according to a fixed ratio, the derivation of which has not been previously documented. Using the implied estimate of the number of publicly-owned LDT's, presented above, and TIUS estimates of the number of utility and commercial LDT's (excluding those used for personal transport), the following distribution has been incorporated into the LDV Fleet Model.

Table E-42: Current and Previous Fleet LDT Allocation

Fleet Type	Number	Current NEMS FLTTSHR	Previous NEMS FLTTSHR
Business	13,285,511	83.5%	73.6%
Government	2,237,302	14.1%	17.8%
Utility	383,421	2.4%	8.8%

Vehicle Distribution Within Fleets

Under the provisions of EPACT, purchases of vehicles by fleets meeting certain criteria are affected by the requirement that a proportion be alternatively fueled. The specific conditions under which these provisions are in effect, and the fleet sizes which are affected are not static, but are subject to revision. Obtaining an accurate estimate of the number of automobiles in fleet service is necessary in order to derive a forecast of the purchase of alternative fuel vehicles mandated under EPACT, and the consequent demand for petroleum, electricity, and alternative fuels used for transportation. Under the previous model, a fixed proportion of annual automobile and light truck sales (which were exogenously obtained) were assigned to business, utility, and government fleets. As the alternative fuel provisions of EPACT attach to fleets at or above a given size, it is important to develop a means of estimating the affected population of vehicles under the current, or any future definition of a "fleet". Due to the dissimilarities of the data available, separate approaches have been developed for light trucks and automobiles, as described below.

Trucks

The proposed approach uses the fleet-size data from the TIUS survey to derive a functional form for estimating the affected population of LDT's in fleets. The applicability of this approach is constrained by the aggregate nature of the survey, but should serve as a good first approximation. The first step is to look at the distribution of trucks by fleet type; only business and utility fleets are considered as all government vehicles are assumed to be affected by the legislation (and are not represented in TIUS). The number of trucks within each considered fleet type, stratified by fleet size, are tabulated below. These distributions are also graphically depicted on the following pages. It is clear from these figures that business and utility fleets have significantly different size characteristics, as is to be expected. Most commercial light trucks exist in fleets of less than 20 vehicles, and are therefore unaffected by EPACT legislation, while the overwhelming majority of utility vehicles are in large fleets.

Table E-43: Light Truck Distribution in Business Fleets

Fleet Size	Number	Percent of Total Defined	Cumulative Percentage: P(n)	Reverse Cumulative: Q(n)
1	5,422,935	43.7%	43.7%	100.0%
2 to 5	4,261,155	34.3%	78.0%	56.3%
6 to 9	799,876	6.4%	84.5%	22.0%
10 to 24	843,262	6.8%	91.3%	15.5%
25 to 99	613,610	4.9%	96.2%	8.7%
100 to 499	295,196	2.4%	98.6%	3.8%
500 or More	176,383	1.4%	100.0%	1.4%
Undefined	873,094			
Total Defined	12,412,417			

Table E-44: Light Truck Distribution in Utility Fleets

Fleet Size	Number	Percent of Total Defined	Cumulative Percentage: P(n)	Reverse Cumulative: Q(n)
1	25,677	6.8%	6.8%	100.0%
2 to 5	18,573	4.9%	11.8%	93.2%
6 to 9	24,296	6.5%	18.2%	88.2%
10 to 24	38,717	10.3%	28.6%	81.8%
25 to 99	59,301	15.8%	44.3%	71.4%
100 to 499	49,294	13.1%	57.5%	55.7%
500 or More	159,804	42.5%	100.0%	42.5%
Undefined	7,759			
Total Defined	375,662			

As the strata defined in the TIUS survey do not correspond to the fleet sizes addressed in

EPACT, it is necessary to derive a functional form for each distribution. This is accomplished by considering the cumulative distribution of fleet trucks P(n), or, more accurately, its complement: Q(n), referred to, for lack of a better term, as the reverse cumulative distribution. This distribution describes the number of trucks in fleet sizes greater than or equal to *n*, as depicted below.

The most straightforward method of estimating a functional form is to transform the data so that it approximates a linear relationship, then use OLS to estimate the coefficients. As the figure above shows, plotting both axes logarithmically produces a reasonable approximation of linearity. This suggests the following form:

$$LN\,Q(N) = K\,LN(N)$$
$$OR$$
$$Q(N) = N^{k}$$

where:

Q(n) = The reverse cumulative distribution: the percentage of trucks in fleets of size greater than or equal to *n*.

Testing this approach with the data described above provides the results tabulated below. The significance of the coefficients and the high R-squared gives confidence that this formulation will provide a satisfactory means of estimating the affected light truck population in business and utility fleets. A plot of these functions over TIUS data is provided below.

Table E-45: Regression Output

	Business	Utility
Constant	0	0
Coefficient (k)	-0.747	-0.111
Standard Error.	0.020	0.008
T-Statistic	-36.63	-13.22
R Squared	0.988	0.937

Applying this function permits a stratification of light trucks into three groups: non-fleet (<20 vehicles), small fleet (20-50 vehicles) and large fleet (>50 vehicles). The distribution of these percentages, by fleet type, are tabulated below. It should be noted, once again, that publicly-owned vehicles (federal, state, and municipal) are not subject to the fleet-size constraints, and are therefore not similarly stratified. Insofar as different components of the publicly-owned fleet of LTD's have different acquisition requirements under EPACT, it is suggested that a sales-weighted average of the requirements be used.

Table E-46: Distribution of LDT's, by Fleet Type and Size (FLTSIZE)

Fleet Size	Index (IFS)	Calculation	Fleet Type	
			Business	Utility
Non-Fleet (<20 LDT's)	1	Q(1) - Q(20)	89.3%	28.4%
Small Fleet (20-50 LDT's)	2	Q(20) - Q(50)	5.3%	6.9%
Large Fleet (>50 LDT's)	3	Q(50)	5.4%	64.7%
Total			**100%**	**100%**

Automobiles

In a report on the characteristics of fleet vehicles in the United States,[65] Oak Ridge Natiional Laboratory notes that no comprehensive nationwide automobile fleet vehicle survey is currently available. This stands in contrast to the abundance of census data available for the analysis of U.S. truck populations, and inhibits the development of a methodology to estimate the number of fleet vehicles covered by EPACT regulations. The *1992 Automotive Fleet Fact Book*,[66] which provides summary characteristics of fleet vehicles, represents the sole source of data used in constructing the following distribution.

Given the limitations of the data, several assumptions and manipulations are necessary to transform the published data into a form commensurate with the needs of the model. It is first assumed that both Government and Utility fleets are large enough to be affected by EPACT regulations, obviating the need for further analysis of their distributions. It is also assumed that the number of vehicles in business fleets should not include employee-owned, daily rental, or individually-leased vehicles, as these are outside the purview of the legislation. This exclusion is accomplished through the use of the function BFLTFRAC, described above. Aggregating business fleet data and subtracting excluded vehicles results in the distribution provided in the

[65] *Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices,* Oak Ridge National Laboratory, ORNL-6717, May 1992.

[66] *Automotive Fleet Fact Book, 1992.* Bobit Publishing Company, pp. 16, 20.

table below. As there are only three data points, this effectively precludes the use of regression analysis to estimate a distribution function for business fleet vehicles. The alternative is to assume the simplest functional form which can be adjusted to approximate the desired distribution. After testing a variety of specifications, the form selected is as follows:

$$Q(N) = \frac{K_3}{LN(N)}$$

where:

Q(n) = The percentage of vehicles in fleets of size greater than or equal to *n*

k_3 = The constant of proportionality, chosen by normalizing the function to 1.0 when $n = 4$; estimated to be 1.386.

Table E-47: 1992 Bobit Fleet Data

Fleet Type	Number of Vehicles (Thousands)
Business Fleets (by Size)	
>= 4 Vehicles	5,261
>= 10 Vehicles	2,820
>= 25 Vehicles	2,323
Government Fleets	504
Utility Fleets	544

This function is graphically displayed below, along with the original data. Applying this function permits a stratification of business fleet automobiles into three groups: non-fleet (<20 vehicles), small fleet (20-50 vehicles) and large fleet (>50 vehicles). The distribution of these percentages is tabulated below.

Table E-48: Percentage of Business Fleet Automobiles (FLTSIZE)

Fleet Size	Index (IFS)	Calculation	Percent
Non-Fleet (<20 Cars)	1	Q(1) - Q(20)	53.7%
Small Fleet (20-50 Cars)	2	Q(20) - Q(50)	10.8%
Large Fleet (>50 Cars)	3	Q(50)	35.4%
Total			**100%**

The incorporation of these modifications will, in all likelihood, not result in significant changes in the output of the NEMS Transportation Model, but will more easily permit the inclusion of users' assumptions and will be able to withstand a higher level of scrutiny of the methodology.

Attachment 5: Light Commercial Truck Model

Data Development for the LCT Model

The primary source of data for this model is the microdata file of the 1992 Truck Inventory and Use Survey (TIUS), which provides numerous details on truck stock and usage patterns at a high level of disaggregation. The data derived from this source are used to allocate and sort the summary truck data presented in the Federal Highway Administration's annual publication of highway statistics, which constitute the baseline from which the NEMS forecast is made. TIUS data are also used to distribute estimated sales of trucks, obtained from the Macroeconomic Model, among the affected models according to their weight class. Finally, the TIUS microdata set is used to construct a characterization of these Light Commercial Trucks, comprising their average annual miles of travel, fuel economy, and distribution among several aggregate industrial groupings chosen for their correspondence with output measures currently being forecast by NEMS. It is expected that projected growth in industrial output will provide a useful proxy for the growth in demand for the services of light commercial trucks. This issue will be addressed later in this section.

Distribution of Truck Stock

The principal source of confusion and double-counting encountered in the truck models stems from differing definitions of what constitutes a light truck among the data sources used by NEMS. In the past, FHWA's estimate of 2-axle, 4-tire trucks have been interpreted as representing light-duty trucks, less than 8,500 lbs, and therefore properly within the purview of the LDV Module. Likewise, sales estimates from the Macro Model have been assumed to represent only LDT's, and have been similarly assigned. On closer examination, neither of these assumptions can be shown to have been justified.

Using the information derived from TIUS, it is estimated that of the 2-axle, 4-tire trucks, approximately 88 percent of the pickup trucks and 85 percent of the other trucks (vans, panel trucks, etc.) fall into that weight range. The remainder properly belong in the newly-established LCT category. Similarly, sales estimates from the Macro Model have been shown to represent sales of trucks under 14,000 lbs., indicating a significant overlap across the LCT weight range and into the medium freight truck category. Using the weight distributions by truck type available from TIUS, a suggested stratification scheme may be proposed. Table E-56, below, presents the TIUS estimates of single-unit truck stock, stratified by axle configuration, body type, and weight. While there are significant discrepancies between FHWA's summary stock figures and those presented below (see Table E-57), it is assumed that the relative distribution of trucks within each grouping is constant, and transferrable between samples.

Table E-49: Distribution of Single-Unit Trucks, From TIUS					
	Total	**Pickup**	**Van**	**SU Light**	**SU Heavy**
2 AX, 2 TIRES EA					
6,000 OR LESS	36,682,877	22,085,491	14,499,647	97,739	0
6 ,001- 10,000	16,476,534	10,195,368	5,909,766	371,400	0
10 ,001- 14,000	95,522	0	0	95,522	0
14 ,001- 16,000	37,980	0	0	37,980	0
16 ,001- 19,500	53,606	0	0	53,606	0
19,501-26,000	434,632	0	0	434,632	0
26 ,001- 33,000	27,359	0	0	0	27,359
33,001 OR MORE	244,863	0	0	0	244,863
Total	54,053,373	32,280,859	20,409,413	1,090,879	272,222
2 AX, 2&4 TIRES					
6,000 OR LESS	374,070	290,142	74,031	9,897	0
6 ,001- 10,000	1,035,862	536,274	89,182	410,406	0
10 ,001- 14,000	246,374	0	0	246,374	0
14 ,001- 16,000	81,897	0	0	81,897	0
16 ,001- 19,500	141,746	0	0	141,746	0
19,501-26,000	1,219,550	0	0	1,219,550	0
26 ,001- 33,000	72,072	0	0	0	72,072
33,001 OR MORE	169,942	0	0	0	169,942
Total	3,341,513	826,416	163,213	2,109,870	242,014
3 AXLES					
6,000 OR LESS	731	0	0	731	0
6 ,001- 10,000	2,123	0	0	2,123	0
10 ,001- 14,000	3,970	0	0	3,970	0
14 ,001- 16,000	2,478	0	0	2,478	0
16 ,001- 19,500	5,342	0	0	5,342	0
19,501-26,000	94,064	0	0	94,064	0
26 ,001- 33,000	7,446	0	0	0	7,446
33,001 OR MORE	329,043	0	0	0	329,043
Total	445,197	0	0	108,708	336,489
4 AXLES OR MORE					
6,000 OR LESS	0	0	0	0	0
6 ,001- 10,000	1,351	0	0	1,351	0
10 ,001- 14,000	1,807	0	0	1,807	0
14 ,001- 16,000	0	0	0	0	0
16 ,001- 19,500	291	0	0	291	0
19,501-26,000	3,024	0	0	3,024	0
26 ,001- 33,000	151	0	0	0	151
33,001 OR MORE	62,084	0	0	0	62,084
Total	68,708	0	0	6,473	62,235

The data above can be used to estimate the fraction of single-unit trucks in the FHWA sample which are less than or equal 10,000 lbs., the upper bound of the LCT weight class. Aggregating the sample numbers and calculating the percentages in the relevant groups provides the winnowing factors in the table below.

Table E-50: Stock Estimates: All Single-Unit Trucks						
Number	**All Trucks**		**Trucks<=10,000 Lbs**		**%<=10k lbs**	
	2A4T	**Other**	**2A4T**	**Other**	**2A4T**	**Other**
Pickups	32,280,859	826,416	32,280,859	826,416	100%	100%
Other	21,772,514	3,029,002	20,878,552	587,721	95.89%	19.40%
Total	*54,053,373*	*3,855,418*	*53,159,411*	*1,414,137*		
Percent	**All Trucks**		**Trucks<=10,000 Lbs**			
	2A4T	**Other**	**2A4T**	**Other**		
Pickups	59.72%	21.44%	60.72%	58.44%		
Other	40.28%	78.56%	39.28%	41.56%		

Similarly, the distributions in Table E-56 can be aggregated to determine the allocation of truck sales obtained from the Macro Model, first splitting off that fraction between 10,000 and 14,000 lbs., and then distributing the remainder between 2-axle, 4-tire trucks and trucks with other axle configurations, as shown below.

Table E-51: Distribution of Light Truck Sales from Macro Model		
	Total	**Percent**
Total SU Trucks <= 14,000 lbs	54,921,221	
Of Which:		
SU Trucks <= 10,000 lbs.	54,573,548	99.37%
Of Which:		
2A4T Trucks <= 10,000 lbs	53,159,411	97.41%
Other SU Trucks <= 10,000 lbs.	1,414,137	2.59%

The next step is to determine the fraction of trucks which exceed the 8,500 lb. lower bound of the LCT weight category. TIUS, unfortunately, does not provide a breakdown of truck stock along those lines, thus requiring the imputing of the appropriate fractions. After consideration of several options, it has been decided to use a simple linear interpolation of the cumulative share of each truck type between 6,000 and 10,000 lbs. The data and resulting shares are provided in Table E-59, below.

Table E-52: Linear Interpolation: Fraction Between 8.5 and 10k lbs

Axle Configuration	Pickups		Other	
2A4T				
	Total	**Percent**	**Total**	**Percent**
<= 6k	22,085,491	68.42%	14,597,386	67.05%
<= 10k	32,280,859	100.00%	20,878,552	95.89%
Total	32,280,859	100.00%	21,772,514	100.00%
Interpolation				
<= 8.5	28,457,596	88.16%	17,762,570	85.08%
8.5-10k	3,823,263	11.84%	3,115,982 *	14.92%
Other				
	Total	**Percent**	**Total**	**Percent**
<= 6k	290,142	35.11%	84,659	14.40%
<= 10k	826,416	100.00%	587,721	100.00%
Total	826,416	100.00%	587,721	100.00%
Interpolation				
<= 8.5	625,313	75.67%	399,073	67.90%
8.5-10k	201,103	24.33%	188,648	32.10%

* The weight range for 2-axle, 4-tire non-pickup trucks is defined to be everything >= 8,500 lbs. This is done to simplify the accounting of the model, due to the small number of these trucks which exceed 10,000 lbs., and to recognize that the purposes to which most of these vans and small panel truck are put would most appropriately be addressed within the Light Commercial Truck Model, rather than in the Highway Freight Model.

In order to simplify the allocation scheme described above, the distribution of stock and sales are presented graphically, in Figures F-16 and F-17, below.

Figure E-1. Distribution of FHWA Single-Unit Truck Stocks

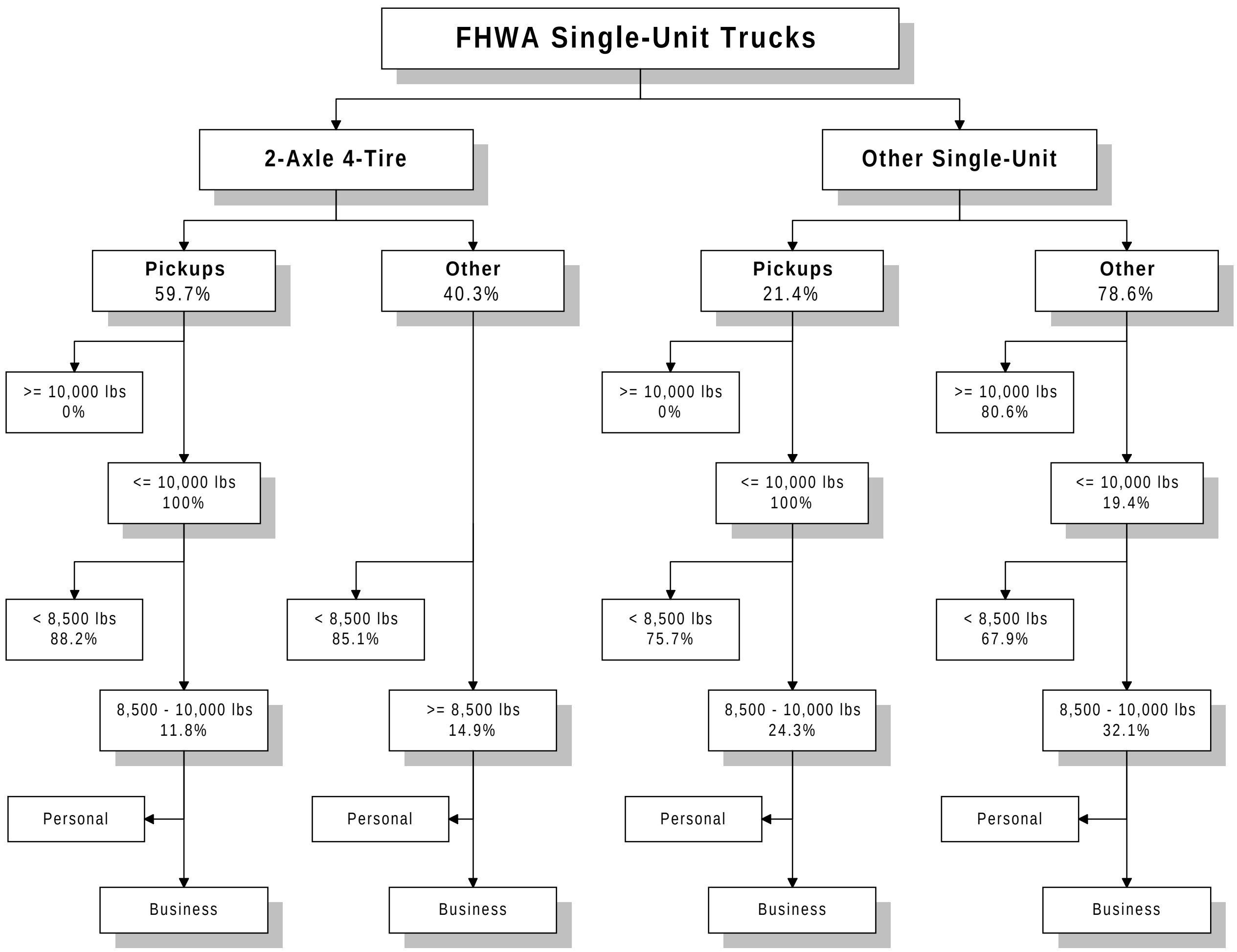
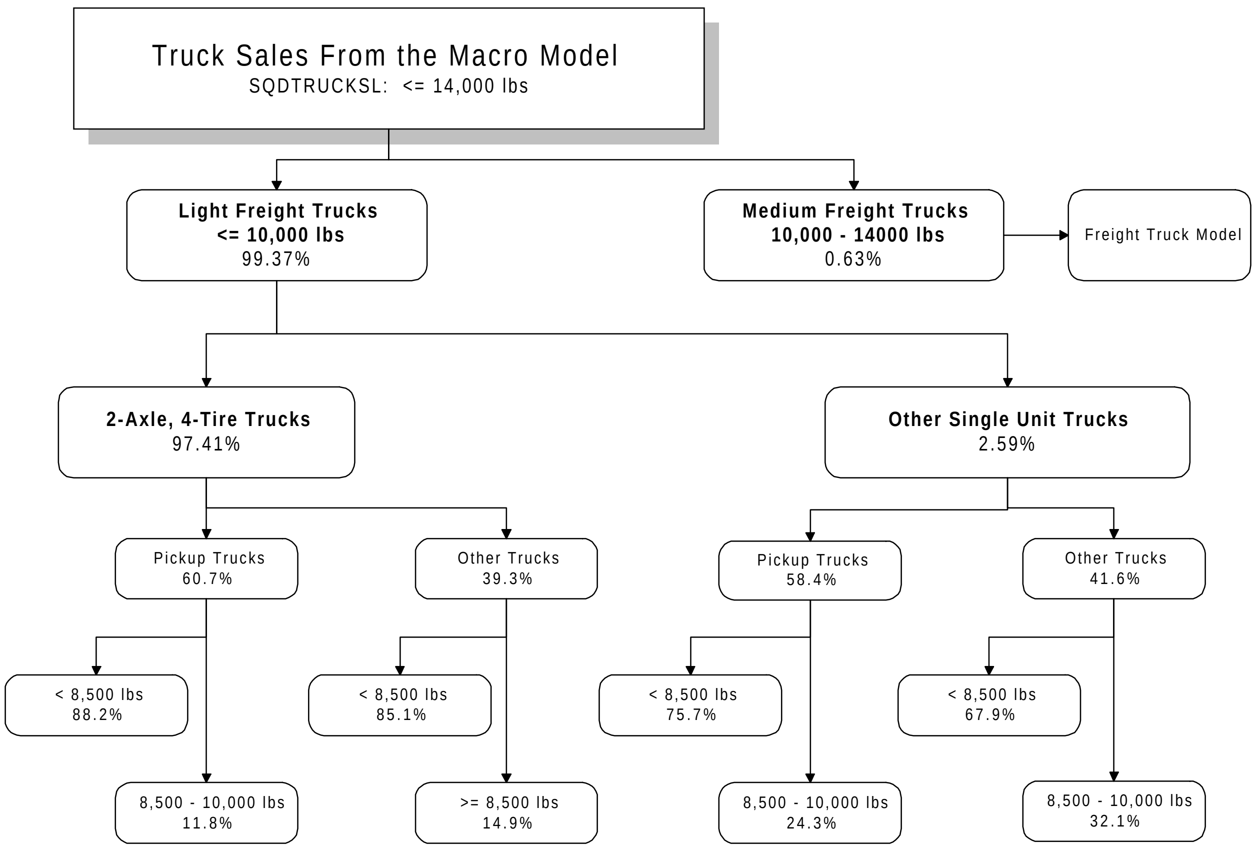


Figure E-2: Distribution of Light Truck Sales



Allocation of Truck Stock Among Industrial Groups

In order to develop a forecast of LCT use which is sensitive to economic activity, it is necessary to allocate the trucks according to their major use. TIUS provides an accounting of trucks within sixteen major use categories, not all of which correspond directly with measures of industrial output generated by NEMS. These categories are therefore aggregated into measures which can be addressed within the NEMS structure, as defined below.

Table E-53: Correspondence of Major Use Categories

TIUS Categories	Aggregate LCT Model Categories
Agriculture or Farm Activities Forestry or Lumber	Agriculture
Mining or Quarry	Mining
Construction Work Contractor Activities	Construction
Manufacturing Wholesale Trade Retail Trade Business Daily Rental Not In Use For Hire Transportation Other One-Way Rental	Manufacturing & Trade
Utilities	Utilities
Personal Transportation	Personal

Detailed tables of the distribution of single-unit trucks among both major-use categories are provided in subsequent tables. These data are used to share-out the four types of truck considered by this model. It is assumed that the relative shares of trucks in the 6 to 10 thousand pound weight range is an acceptable proxy for the relative populations of the 8.5 to 10 thousand pound vehicles. The aggregate numbers and the resulting percentages are provided in the following table. It is further assumed that the percentage figures used to allocate the LCT's remain constant, at least until the publication of the next TIUS. These are rather strong assumptions, but appear justified by the paucity of other sources of detailed information about the population and operating characteristics of Light Commercial Trucks.

Table E-54: Number of Trucks, 6,000-10,000 lbs GVW				
Major Use	**2 Axle, 4 Tire**		**Other Single-Unit**	
	Pickup	**Other**	**Pickup**	**Other**
Agriculture	1,419,306	316,281	104,408	66,853
Mining	79,925	40,414	5,664	3,278
Construction	1,197,648	800,004	78,721	120,343
Trade	1,064,497	1,592,306	113,801	231,008
Utilities	84,334	127,476	3,378	9,334
Personal	6,349,658	4,298,573	230,302	72,246
Total	10,195,368	7,175,054	536,274	503,062
Percent	**2 Axle, 4 Tire**		**Other Single-Unit**	
	Pickup	**Other**	**Pickup**	**Other**
Agriculture	13.9%	4.4%	19.5%	13.3%
Mining	0.8%	0.6%	1.1%	0.7%
Construction	11.7%	11.1%	14.7%	23.9%
Trade	10.4%	22.2%	21.2%	45.9%
Utilities	0.8%	1.8%	0.6%	1.9%
Personal	62.3%	59.9%	42.9%	14.4%

Operating Characteristics

The operating characteristics of LCT's relevant to forecasting energy demand are the average annual miles per truck driven within each major use category and the corresponding average fuel economy. An extensive sequence of sorting and tabulating procedures has resulted in Table E-62, which provides an estimate of average travel demand for trucks between 6 and 10 thousand pounds. As is done in apportioning trucks among use categories, it is assumed that these driving characteristics are uniform across the weight class, and therefore accurately represent the more narrow LCT category.

Table E-55: Average Annual Miles, by Major Use (1992 TIUS) Aggregated for NEMS				
Major Use	**Single-Unit Trucks, 6,000 - 10,000 Lbs.**			
	2 Axle, 4 Tire		**Other Single-Unit**	
	Pickup	**Other**	**Pickup**	**Other**
Agriculture	11,920	8,569	15,197	7,054
Mining	20,231	24,871	18,520	17,786
Construction	15,909	15,195	13,043	10,074
Trade	13,313	15,394	10,009	11,832
Utilities	13,023	13,776	9,947	9,996
Personal	9,980	10,148	8,429	5,852

Estimating the average fuel economy of these trucks is considerably more problematic, and requires additional assumptions and calculations. While TIUS requires the operators of larger trucks to explicitly state their average fuel economy, the census form for smaller trucks requires only that operators identify an MPG range in which their trucks operated in the prior year. It is therefore necessary to combine these two sets of survey responses on the most aggregate level, and then use more robust estimation methods to determine the mean characteristics of each group. The aggregate tabulation of trucks according to major use, vehicle type, and fuel economy is provided in tables below. Again, the attributes of 6 to 10 thousand pound trucks are assumed to represent those of the 8.5 to 10 thousand pound group.

Estimating the average characteristics of these grouped data involves the use of a trimmed mean: first determining the quartiles of each distribution, calculating the interquartile range (IQR), and then estimating the biweighted harmonic mean of the sample. These quartiles are presented in Table E-63. Determining the biweighted mean involves calculating a weighting factor which is a function of an observation's deviation from the median of the sample $\hat{X}$, as shown below.

$$w(X) = (1 - Z^2)^2 \qquad |Z| \leq 1$$

$$w(X) = 0 \qquad |Z| > 1$$

$$\text{where:} \qquad Z = \frac{X - \hat{X}}{3(IQR)}$$

where *w* is the weighting factor, and X represents the midpoint of each MPG range. The biweighted mean is then calculated as follows:

$$\bar{X} = \left[\frac{\sum_k N_k \left(\frac{1}{X_k} \right) w(X_k)}{\sum_k N_k w(X_k)} \right]^{-1}$$

where N_k is the population of MPG range *k*. The inverting of the MPG value in the equation, and subsequent inversion of the result is intended to provide an estimate of the harmonic mean of the sample. This results in a first approximation of the fuel economy of LCT's, and is tabulated in Table F-64. These values are subsequently used to replace the value of the sample median in the calculation of Z, above, and the procedure is iterated until the MPG estimates converge. The results of this iterative procedure are presented in Table E-64.

Table E-56: MPG Distributions, By Quartile

	2 Axle, 4 Tire		Other	
	Pickup	Other	Pickup	Other
Agriculture				
Q25	10.9	8.0	10.0	8.0
Median	13.1	10.8	12.3	10.0
Q75	16.5	13.6	17.4	12.5
IQR	5.6	5.6	7.3	4.4
Mean	12.83	9.26	11.87	9.02
Mining				
Q25	11.5	11.1	11.5	9.2
Median	13.5	12.5	12.0	10.7
Q75	16.2	14.2	12.6	13.0
IQR	4.7	3.1	1.1	3.8
Mean	13.18	12.15	12.00	10.25
Construction				
Q25	11.7	10.6	10.5	8.0
Median	13.8	12.5	13.4	9.8
Q75	16.9	15.7	15.4	11.7
IQR	5.2	5.1	4.9	3.7
Mean	13.50	11.96	12.74	9.12
Trade				
Q25	11.8	10.4	10.2	8.1
Median	14.0	12.7	12.6	10.1
Q75	17.3	15.8	21.0	12.5
IQR	5.6	5.4	10.9	4.3
Mean	13.63	11.84	12.70	9.28
Utilities				
Q25	11.8	9.6	11.7	7.3
Median	14.1	12.0	12.7	9.8
Q75	16.8	14.4	17.4	11.9
IQR	4.9	4.8	5.7	4.6
Mean	13.49	10.86	13.46	8.84
Personal				
Q25	11.8	12.1	10.2	9.6
Median	14.1	14.4	12.4	11.5
Q75	17.4	17.7	16.8	13.9
IQR	5.7	5.6	6.6	4.2
Mean	13.73	14.05	12.31	10.95

Table E-57: Average MPG: Biweighted Mean Iterated				
Major Use	2 Axle, 4 Tire			
	Pickup	Other	Pickup	Other
Agriculture	12.77	8.75	11.79	8.66
Mining	13.12	11.92	12.00	10.10
Construction	13.45	11.79	12.58	8.92
Trade	13.55	11.57	12.71	8.98
Utilities	13.33	10.25	13.57	8.65
Personal	13.67	13.99	12.29	10.78

The above tables effectively describe Light Commercial Trucks for the purpose of forecasting their demand for travel and consumption of fuel. In the following section, the FHWA stock numbers will be incorporated, and measures of industrial output will be used to test the responsiveness of the proposed model to variations in economic conditions.

Incorporation of FHWA Baseline Data

In order to track the activities of LCT's, and derive an estimate of scrappage rates, historical figures from FHWA have been considered. The stock of trucks and their annual miles of travel are presented below. It should be noted that, beginning with the 1994 edition of FHWA's *Highway Statistics*, a revised definition of 2-axle, 4-tire trucks has been implemented, removing such vehicles as vans and sport-utility vehicles from the "automobile" category and placing them in the "single-

Table E-58: Single-Unit Truck Characteristics, from FHWA						
	Stock		VMT (Millions)		VMT per Truck	
	2A4T	Other	2A4T	Other	2A4T	Other
1985	46,125,097	3,927,412	490,274	46,980	10,629	11,962
1986	47,319,902	4,024,842	510,178	48,413	10,781	12,029
1987	48,816,260	3,883,694	543,615	49,537	11,136	12,755
1988	50,524,830	3,957,319	575,411	51,239	11,389	12,948
1989	51,644,255	4,102,863	596,024	52,969	11,541	12,910
1990	52,932,510	4,243,044	614,491	53,443	11,609	12,595
1991	53,210,253	4,265,307	624,982	53,787	11,746	12,610
1992	53,844,501	4,316,148	637,049	53,691	11,831	12,440
1993	55,710,076	4,526,004	661,546	56,781	11,875	12,546
1994	57,141,967	4,724,608	669,321	61,284	11,713	12,971
1995	57,897,398	5,203,810	686,977	62,706	11,865	12,050

unit truck" category.

This change in definition has required making incremental adjustments to 2A4T truck stocks in the preceding years. This has been accomplished by considering the change in 2A4T populations for the year 1993--the only overlapping year in which stock numbers under both sets of definitions are provided. The current definition increases truck population by 36.2 percent over the prior tabulation; this is therefore considered to be uniform across time, and previous years' stocks have been similarly augmented. The number of miles traveled is also adjusted, through the expedient of assuming that every vehicle transferred from the automobile category travels an average number of miles defined by the overall average for automobiles. The above table represents single-unit trucks of all weight classes. The stratification procedures described in the previous section is subsequently imposed in order to derive an estimate of Light Commercial Truck stock within each truck type and major-use category. The distribution among truck types is presented below, in Table E-66.

Table E-59: Number of Light Commercial Trucks (by Type)

	2A4T		Other	
	Pickup	Other	Pickup	Other
1985	3,262,486	2,658,945	204,858	192,171
1986	3,346,996	2,727,821	209,940	196,938
1987	3,452,835	2,814,081	202,578	190,032
1988	3,573,685	2,912,574	206,418	193,634
1989	3,652,863	2,977,105	214,010	200,756
1990	3,743,983	3,051,368	221,322	207,615
1991	3,763,628	3,067,379	222,483	208,704
1992	3,808,489	3,103,941	225,135	211,192
1993	3,940,444	3,211,484	236,081	221,460
1994	4,041,723	3,294,028	246,441	231,178
1995	4,095,156	3,337,576	271,436	254,626

The number of trucks in each year is assumed to represent the net effect of a fixed scrappage rate applied to the previous year's stock, and the allocation of new purchases from the Macro Model. Because light truck purchases are exogenously supplied, the scrappage rate must be inferred. The table below represents the allocation of new LCT stock by vehicle type. Allocation among major-use groups is detailed in subsequent tables. A fixed scrappage rate is then calculated for the two classes of single-unit trucks, combining pickups and others, and averaging across the years 1986 to 1994. This results in an average annual scrappage rate of 6.77 percent for 2-axle 4-tire trucks, and 6.54 percent for other single-unit trucks. This percentage is applied uniformly across the forecast years. The purpose of this exercise is to enable the model to accommodate the incorporation of more fuel-efficient trucks over the course of the forecast.

Table E-60: New Purchases of Light Commercial Trucks (by Type)				
	2A4T		Other	
	Pickup	Other	Pickup	Other
1985	307,831	250,884	16,192	15,189
1986	320,501	261,210	16,858	15,814
1987	323,634	263,763	17,023	15,969
1988	337,556	275,110	17,755	16,656
1989	326,905	266,430	17,195	16,130
1990	305,929	249,334	16,092	15,095
1991	287,665	234,449	15,131	14,194
1992	324,257	264,272	17,056	16,000
1993	374,857	305,511	19,717	18,496
1994	421,693	343,682	22,181	20,807
1995	424,944	346,331	22,352	20,968

Forecasting VMT and MPG

In order to estimate fuel demand by LCT's, it is necessary to develop a forecast of two elements: the total travel demanded within each major-use group, and the average fuel economy of the trucks. Again, the FHWA data provides little guidance in the allocation of VMT and MPG among light commercial trucks; assumptions based on TIUS stratifications are therefore used.

Using the disaggregated FHWA data on the number of LCT's in 1992, and the TIUS data on the average number of miles per truck in the same year, a baseline VMT demand for 1992 may be constructed for each industrial group. Each baseline figure is then multiplied by an index of corresponding macroeconomic output (1992 = 1.0), to estimate the growth in VMT for each group. Personal travel is the exception, being adjusted by an index of personal travel from the LDV Model. The indexed growth in industrial output is depicted in the figure above. The figure on the following page depicts total VMT forecasts by truck type.

Estimates of fuel economy for trucks in each sector are obtained in a similar manner. Absent disaggregate time-trend data on LCT fuel economy, it is assumed that the 1992 TIUS values derived above satisfactorily describe each class of truck. It is further assumed that new trucks acquired after 1992 experience the same proportional change in MPG as do the light-duty trucks as represented in the LDV Model. Each MPG within the LCT Model is therefore adjusted by an index of LDT fuel economy, with 1992 = 1.0. These new, more efficient trucks are incorporated into the previous year's scrappage-adjusted stock using a stock-weighted harmonic average of fuel economies. This is depicted in the aggregate, below, where a VMT-weighted harmonic average was used to combine industrial groups, resulting in a forecast of stock MPG by truck type.

Energy Demand

Having an estimate of travel demand and fuel economy for each truck type and industrial group, it is a simple step to calculate the energy required to meet this demand. The figures below represent the aggregate demand for energy, by truck type, for LCT's. It is a relatively small, but not negligible, amount; rising from approximately 1 quad in 1990 to near 2 quads in 2015. The figures on the following page show how this energy demand is distributed among the major-use groups. Personal travel represents roughly half of all energy demand within this class of truck, with much of the remainder being allocated between Construction and Manufacturing & Trade.

This proposed model provides, by necessity, a rough approximation of the characteristics and performance of a relatively small category of trucks. Improvements in the model and the narrowing of assumptions will probably have to wait until the issuance of the next Truck Inventory and Use Survey, or the provision of more detailed statistics by FHWA.

1992 TIUS Estimated Truck Registration Comparison with Federal Highway Administration Truck Registration

The Federal Highway Administration (FHWA) estimate of the number of private and commercial trucks registered is based on a calendar year summary report from each state. It reflects differences in truck definitions used by each state for vehicle registration from those used in TIUS.

Table E-61: 1992 TIUS vs. FHWA

State	TIUS	FHWA	Difference
	(Numbers in Thousands)		
US	59,201	43,675	15,525
AL	1,167	1,075	92
AK	201	169	31
AZ	1,000	787	213
AR	749	512	237
CA	7,150	4,718	2,433
CO	1,093	722	371
CT	544	109	435
DE	173	121	52
DC	29	11	19
FL	2,673	1,938	735
GA	1,644	1,709	(65)
HI	280	95	185
ID	467	401	66
IL	2,272	1,325	947
IN	1,414	1,159	256
IA	931	741	190
KS	1,002	642	360
KY	1,016	984	32
LA	1,124	1,050	74
ME	339	211	127
MD	941	583	358
MA	879	467	412
MI	2,166	1,538	628
MN	1,156	708	448
MS	648	433	215
MO	1,357	1,156	201
MT	372	348	24

Table E-61: 1992 TIUS vs. FHWA			
State	TIUS	FHWA	Difference
	(Numbers in Thousands)		
NE	534	442	92
NV	388	286	102
NH	306	189	118
NJ	1,099	353	746
NM	581	492	89
NY	2,000	1,191	809
NC	1,760	1,439	321
ND	291	251	39
OH	2,189	1,635	554
OK	1,080	927	153
OR	1,059	592	467
PA	2,368	1,558	809
RI	159	98	61
SC	841	617	224
SD	295	279	16
TN	1,463	857	605
TX	4,373	3,803	570
UT	510	429	81
VT	157	112	46
VA	1,517	1,230	286
WA	1,542	1,288	254
WV	477	456	21
WI	1,197	1,221	(24)
WY	235	222	13

Distribution of Single-Unit Truck Stock

Table E-62: Distribution of 2-Axle, 4-Tire Trucks by Major Use and Weight

Pickup Trucks, by Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 -16,000	16,001 -19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Total	32,280,857	22,085,490	10,195,367	0	0	0	0	0	0
Agriculture or Farm Activities	2,267,891	937,018	1,330,873	0	0	0	0	0	0
Forestry or Lumber	150,014	61,581	88,433	0	0	0	0	0	0
Construction Work	1,049,648	520,703	528,945	0	0	0	0	0	0
Contractor Activities	1,623,799	955,096	668,703	0	0	0	0	0	0
Manufacturing	338,911	189,362	149,549	0	0	0	0	0	0
Wholesale Trade	269,741	190,115	79,626	0	0	0	0	0	0
Retail Trade	692,200	461,164	231,036	0	0	0	0	0	0
Business Use	1,186,238	795,568	390,670	0	0	0	0	0	0
Utilities	209,452	125,118	84,334	0	0	0	0	0	0
Mining or Quarry	92,084	12,159	79,925	0	0	0	0	0	0
Daily Rental	34,916	3,507	31,409	0	0	0	0	0	0
Not In Use	551,553	383,412	168,141	0	0	0	0	0	0
For Hire Transportation	52,733	38,668	14,065	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	1,792	1,792	0	0	0	0	0	0	0
Personal Transportation	23,759,885	17,410,227	6,349,658	0	0	0	0	0	0

Table E-63: Distribution of 2-Axle, 4-Tire Trucks by Major Use and Weight									
Other Single-Unit Trucks, by Major Use	**Total**	**Gross Vehicle Weight (Lbs.)**							
		6,000 or Less	**6,001 - 10,000**	**10,001 - 14,000**	**14,001 -16,000**	**16,001 - 19,500**	**19,501 - 26,000**	**26,001 - 33,000**	**33,001 or More**
Total	21,772,510	14,597,388	6,281,165	95,520	37,979	53,606	434,631	27,359	244,862
Agriculture or Farm Activities	410,505	109,687	141,046	5,464	5,134	23,838	96,743	2,304	26,289
Forestry or Lumber	22,915	7,451	4,707	454	192	749	8,528	225	609
Construction Work	390,414	144,592	164,320	12,054	2,309	6,716	49,089	3,488	7,846
Contractor Activities	976,763	422,582	491,968	9,323	2,832	1,929	38,510	744	8,875
Manufacturing	205,174	100,217	73,168	3,750	2,262	1,476	19,751	2,565	1,985
Wholesale Trade	480,380	217,272	194,978	6,914	1,094	3,183	44,847	5,342	6,750
Retail Trade	895,807	521,579	302,067	11,725	3,421	908	44,372	1,852	9,883
Business Use	1,497,535	917,823	512,825	14,580	7,264	2,565	29,280	2,288	10,910
Utilities	195,288	67,812	99,889	7,886	4,465	1,193	12,440	495	1,108
Mining or Quarry	52,521	12,106	32,726	147	488	139	5,575	89	1,251
Daily Rental	195,002	141,659	39,550	2,024	363	0	9,049	1,338	1,019
Not In Use	277,168	129,822	87,921	3,513	2,543	3,372	25,300	2,298	22,399
For Hire Transportation	112,495	45,299	23,077	8,046	2,724	3,877	21,023	3,875	4,574
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	2,485	0	2,234	17	0	0	0	0	234
Personal Transportation	16,058,058	11,759,487	4,110,689	9,623	2,888	3,661	30,124	456	141,130

Table E-64: Distribution of Other Trucks by Major Use and Weight									
Pickup Trucks, by Major Use	**Total**	**Gross Vehicle Weight (Lbs.)**							
		6,000 or Less	**6,001 - 10,000**	**10,001 - 14,000**	**14,001 -16,000**	**16,001 -19,500**	**19,501 - 26,000**	**26,001 - 33,000**	**33,001 or More**
Total	829,477	293,203	536,274	0	0	0	0	0	0
Agriculture or Farm Activities	136,899	32,686	104,213	0	0	0	0	0	0
Forestry or Lumber	4,064	3,869	195	0	0	0	0	0	0
Construction Work	40,665	13,032	27,633	0	0	0	0	0	0
Contractor Activities	67,095	16,007	51,088	0	0	0	0	0	0
Manufacturing	15,046	10,250	4,796	0	0	0	0	0	0
Wholesale Trade	10,971	4,532	6,439	0	0	0	0	0	0
Retail Trade	26,109	1,881	24,228	0	0	0	0	0	0
Business Use	104,232	33,933	70,299	0	0	0	0	0	0
Utilities	5,612	2,234	3,378	0	0	0	0	0	0
Mining or Quarry	6,348	684	5,664	0	0	0	0	0	0
Daily Rental	2,821	2,821	0	0	0	0	0	0	0
Not In Use	25,814	17,775	8,039	0	0	0	0	0	0
For Hire Transportation	1,528	1,528	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	0	0	0	0	0	0	0	0	0
Personal Transportation	382,273	151,971	230,302	0	0	0	0	0	0

Table E-65: Distribution of Other Trucks by Major Use and Weight

Other Single-Unit Trucks, by Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 -16,000	16,001 -19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Total	3,033,101	88,758	503,062	252,150	84,377	147,378	1,316,638	79,669	561,069
Agriculture or Farm Activities	607,046	4,052	63,688	25,315	14,877	66,596	328,713	11,008	92,797
Forestry or Lumber	48,625	0	3,165	4,331	1,148	3,065	22,467	568	13,881
Construction Work	415,318	2,187	55,000	24,817	11,383	10,320	165,356	7,355	138,900
Contractor Activities	260,603	1,709	65,343	37,739	8,011	10,768	108,512	5,668	22,853
Manufacturing	133,231	0	27,007	11,376	1,591	2,965	54,014	6,262	30,016
Wholesale Trade	268,484	11,975	45,929	18,980	6,274	4,551	134,448	13,275	33,052
Retail Trade	281,472	3,266	58,877	29,972	8,997	6,303	129,628	11,475	32,954
Business Use	286,903	3,198	70,163	37,765	12,388	8,469	91,839	5,689	57,392
Utilities	120,447	0	9,334	21,719	4,490	4,017	69,957	3,064	7,866
Mining or Quarry	43,562	376	3,278	3,100	1,738	1,153	15,313	661	17,943
Daily Rental	48,880	1,005	811	12,203	0	4,859	22,551	2,450	5,001
Not In Use	94,829	5,428	18,852	2,082	3,488	7,346	38,659	3,078	15,896
For Hire Transportation	204,859	0	8,923	10,525	5,808	8,345	89,051	8,112	74,095
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	7,043	0	446	1,787	96	28	4,359	0	327
Personal Transportation	211,799	-55,562	72,246	10,439	4,088	8,593	41,771	1,004	18,096

Table E-66: Distribution of 2-Axle, 4-Tire Trucks by Major Use and Weight

Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 - 16,000	16,001 - 19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Pickup Trucks									
Agriculture	2,417,905	998,599	1,419,306	0	0	0	0	0	0
Mining	92,084	12,159	79,925	0	0	0	0	0	0
Construction	2,673,447	1,475,799	1,197,648	0	0	0	0	0	0
Trade	3,128,084	2,063,588	1,064,496	0	0	0	0	0	0
Utilities	209,452	125,118	84,334	0	0	0	0	0	0
Personal	23,759,885	17,410,227	6,349,658	0	0	0	0	0	0
Other Single-Unit Trucks									
Agriculture	433,420	117,138	145,753	5,918	5,326	24,587	105,271	2,529	26,898
Mining	52,521	12,106	32,726	147	488	139	5,575	89	1,251
Construction	1,367,177	567,174	656,288	21,377	5,141	8,645	87,599	4,232	16,721
Trade	3,666,046	2,073,671	1,235,820	50,569	19,671	15,381	193,622	19,558	57,754
Utilities	195,288	67,812	99,889	7,886	4,465	1,193	12,440	495	1,108
Personal	16,058,058	11,759,487	4,110,689	9,623	2,888	3,661	30,124	456	141,130

Table E-67: Distribution of Other Trucks by Major Use and Weight										
Major Use	**Total**	**Gross Vehicle Weight (Lbs.)**								
		6,000 or Less	**6,001 - 10,000**	**10,001 - 14,000**	**14,001 - 16,000**	**16,001 - 19,500**	**19,501 - 26,000**	**26,001 - 33,000**	**33,001 or More**
Pickups									
Agriculture	140,963	36,555	104,408	0	0	0	0	0	0
Mining	6,348	684	5,664	0	0	0	0	0	0
Construction	107,760	29,039	78,721	0	0	0	0	0	0
Trade	186,521	72,720	113,801	0	0	0	0	0	0
Utilities	5,612	2,234	3,378	0	0	0	0	0	0
Personal	382,273	151,971	230,302	0	0	0	0	0	0
Other Single-Unit									
Agriculture	655,671	4,052	66,853	29,646	16,025	69,661	351,180	11,576	106,678
Mining	43,562	376	3,278	3,100	1,738	1,153	15,313	661	17,943
Construction	675,921	3,896	120,343	62,556	19,394	21,088	273,868	13,023	161,753
Trade	1,325,701	24,872	231,008	124,690	38,642	42,866	564,549	50,341	248,733
Utilities	120,447	0	9,334	21,719	4,490	4,017	69,957	3,064	7,866
Personal	211,799	55,562	72,246	10,439	4,088	8,593	41,771	1,004	18,096

Fuel Economy of Light Commercial Trucks

Table E-68: Distribution of Light Commercial Trucks by MPG												
Miles per Gallon	AGRICULTURE				MINING				CONSTRUCTION			
	2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations	
	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other
Less Than 5	0	11,586	0	2,157	0	1,304	0	40	0	6,009	0	1,695
6.0 - 6.9	2,249	37,908	6,233	6,559	0	1,258	0	42	0	22,340	493	10,669
7.0 - 7.9	47,422	41,985	4,863	14,519	1,566	3,491	0	629	17,069	44,871	1,520	32,174
9,0 - 10.9	319,048	54,325	28,961	19,405	13,148	2,970	271	1,110	171,259	150,295	23,296	34,899
11.0 - 12.9	321,488	54,229	18,398	8,554	20,774	13,312	5,041	632	302,322	221,162	10,420	20,910
13.0 - 14.9	266,650	33,385	7,596	4,900	19,671	10,986	351	309	280,306	116,567	19,477	5,652
15.0 - 20.9	436,552	45,033	31,111	8,924	24,496	5,073	0	514	392,149	189,693	23,516	9,598
21.0 - 24.9	20,643	1,557	7,246	0	271	0	0	0	25,983	22,077	0	0
25.0 - 29.9	4,195	150	0	174	0	0	0	0	2,343	2,849	0	0
30 Or More	1,060	666	0	0	0	0	0	0	6,218	1,914	0	0

Table E-69: Distribution of Light Commercial Trucks by MPG

Miles per Gallon	TRADE				UTILITIES				PERSONAL			
	2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations	
	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other
Less Than 5	1,327	12,125	0	3,676	0	3,946	0	79	579	2,852	0	294
6.0 - 6.9	0	61,177	0	25,386	0	6,984	0	2,007	1,969	9,642	1,566	2,286
7.0 - 7.9	31,564	117,844	10,543	43,261	6,072	13,822	0	1,595	61,712	23,772	8,881	8,507
9,0 - 10.9	131,515	256,935	29,328	61,669	10,249	20,388	266	2,553	993,076	518,874	75,913	19,783
11.0 - 12.9	241,581	341,049	19,775	37,485	11,357	33,365	1,692	1,702	1,380,887	890,383	40,580	16,678
13.0 - 14.9	219,022	262,500	10,410	11,880	27,177	20,653	0	1,038	1,387,827	1,015,041	23,548	10,683
15.0 - 20.9	381,479	351,819	13,460	31,591	28,437	22,706	1,420	215	2,317,935	1,636,196	73,846	11,313
21.0 - 24.9	21,295	57,959	28,193	177	771	1,800	0	145	178,123	138,696	4,662	45
25.0 - 29.9	3,118	2,288	0	163	271	45	0	0	18,133	27,188	0	0
30 Or More	0	884	0	0	0	236	0	0	9,418	4,133	1,305	0

Major-Use Distribution of LCT's

Table E-70: Light Commercial Truck Stock: Stratification by Major Use Group

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
2A4T Pickup											
Agriculturee	454,174	465,938	480,672	497,496	508,518	521,203	523,938	530,183	548,553	562,652	570,090
Mining	25,576	26,238	27,068	28,015	28,636	29,350	29,504	29,856	30,890	31,684	32,103
Construction	383,244	393,171	405,604	419,800	429,101	439,805	442,113	447,383	462,883	474,780	481,057
Trade	340,636	349,459	360,510	373,128	381,395	390,909	392,960	397,644	411,421	421,996	427,575
Utilities	26,987	27,686	28,561	29,561	30,216	30,969	31,132	31,503	32,595	33,432	33,874
Personal	2,031,871	2,084,504	2,150,420	2,225,685	2,274,997	2,331,746	2,343,981	2,371,921	2,454,102	2,517,178	2,550,456
Total	*3,262,486*	*3,346,996*	*3,452,835*	*3,573,685*	*3,652,863*	*3,743,983*	*3,763,628*	*3,808,489*	*3,940,444*	*4,041,723*	*4,095,156*
2A4T Non-Pickup											
Agriculture	117,208	120,244	124,046	128,388	131,233	134,506	135,212	136,824	141,564	145,203	147,122
Mining	14,977	15,365	15,851	16,405	16,769	17,187	17,277	17,483	18,089	18,554	18,799
Construction	296,467	304,147	313,764	324,746	331,941	340,221	342,007	346,083	358,074	367,277	372,133
Trade	590,080	605,365	624,508	646,366	660,687	677,167	680,720	688,834	712,701	731,019	740,683
Utilities	47,240	48,464	49,997	51,746	52,893	54,212	54,497	55,146	57,057	58,524	59,297
Personal	1,592,973	1,634,237	1,685,915	1,744,922	1,783,583	1,828,074	1,837,666	1,859,570	1,924,000	1,973,451	1,999,541
Total	*2,658,945*	*2,727,821*	*2,814,081*	*2,912,574*	*2,977,105*	*3,051,368*	*3,067,379*	*3,103,941*	*3,211,484*	*3,294,028*	*3,337,576*
Other Pickup											
Agriculture	39,884	40,874	39,440	40,188	41,666	43,089	43,316	43,832	45,963	47,980	52,846
Mining	2,164	2,217	2,140	2,180	2,260	2,338	2,350	2,378	2,493	2,603	2,867
Construction	30,072	30,818	29,737	30,301	31,415	32,488	32,659	33,048	34,655	36,176	39,845
Trade	43,472	44,551	42,988	43,803	45,414	46,966	47,212	47,775	50,098	52,296	57,601
Utilities	1,290	1,322	1,276	1,300	1,348	1,394	1,401	1,418	1,487	1,552	1,710
Personal	87,976	90,158	86,997	88,646	91,906	95,046	95,545	96,684	101,385	105,834	116,568
Total	*204,858*	*209,940*	*202,578*	*206,418*	*214,010*	*221,322*	*222,483*	*225,135*	*236,081*	*246,441*	*271,436*
Other Non-Pickup											
Agriculture	25,538	26,172	25,254	25,732	26,679	27,590	27,735	28,066	29,430	30,722	33,838
Mining	1,252	1,283	1,238	1,262	1,308	1,353	1,360	1,376	1,443	1,506	1,659
Construction	45,971	47,112	45,460	46,321	48,025	49,666	49,926	50,522	52,978	55,303	60,912
Trade	88,246	90,435	87,263	88,918	92,188	95,338	95,838	96,980	101,696	106,158	116,925
Utilities	3,566	3,654	3,526	3,593	3,725	3,852	3,872	3,919	4,109	4,289	4,724
Personal	27,598	28,283	27,291	27,808	28,831	29,816	29,973	30,330	31,804	33,200	36,567
Total	*192,171*	*196,938*	*190,032*	*193,634*	*200,756*	*207,615*	*208,704*	*211,192*	*221,460*	*231,178*	*254,626*

Table E-71: LCT Sales: Stratification by Major Use Group

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
2A4T Pickup											
Agriculture	42,853	44,617	45,053	46,991	45,509	42,589	40,046	45,140	52,184	58,704	59,157
Mining	2,413	2,513	2,537	2,646	2,563	2,398	2,255	2,542	2,939	3,306	3,331
Construction	36,161	37,649	38,017	39,653	38,402	35,937	33,792	38,090	44,034	49,536	49,918
Trade	32,141	33,463	33,791	35,244	34,132	31,942	30,035	33,856	39,139	44,029	44,368
Utilities	2,546	2,651	2,677	2,792	2,704	2,531	2,380	2,682	3,101	3,488	3,515
Personal	191,717	199,607	201,558	210,229	203,596	190,532	179,157	201,947	233,461	262,629	264,654
Total	307,831	320,501	323,634	337,556	326,905	305,929	287,665	324,257	374,857	421,693	424,944
2A4T Non-Pickup											
Agriculture	11,059	11,514	11,627	12,127	11,744	10,991	10,335	11,649	13,467	15,150	15,267
Mining	1,413	1,471	1,486	1,550	1,501	1,404	1,321	1,489	1,721	1,936	1,951
Construction	27,973	29,124	29,409	30,674	29,706	27,800	26,141	29,466	34,064	38,320	38,615
Trade	55,677	57,968	58,535	61,053	59,127	55,333	52,029	58,648	67,800	76,271	76,859
Utilities	4,457	4,641	4,686	4,888	4,734	4,430	4,165	4,695	5,428	6,106	6,153
Personal	150,305	156,491	158,020	164,819	159,618	149,376	140,458	158,325	183,031	205,900	207,487
Total	250,884	261,210	263,763	275,110	266,430	249,334	234,449	264,272	305,511	343,682	346,331
Other Pickup											
Agriculture	3,152	3,282	3,314	3,457	3,348	3,133	2,946	3,321	3,839	4,318	4,352
Mining	171	178	180	188	182	170	160	180	208	234	236
Construction	2,377	2,475	2,499	2,606	2,524	2,362	2,221	2,504	2,894	3,256	3,281
Trade	3,436	3,577	3,612	3,768	3,649	3,415	3,211	3,619	4,184	4,707	4,743
Utilities	102	106	107	112	108	101	95	107	124	140	141
Personal	6,954	7,240	7,311	7,625	7,384	6,911	6,498	7,325	8,468	9,526	9,599
Total	16,192	16,858	17,023	17,755	17,195	16,092	15,131	17,056	19,717	22,181	22,352
Other Non-Pickup											
Agriculture	2,019	2,102	2,122	2,213	2,144	2,006	1,886	2,126	2,458	2,765	2,786
Mining	99	103	104	109	105	98	92	104	121	136	137
Construction	3,634	3,783	3,820	3,984	3,859	3,611	3,396	3,827	4,425	4,978	5,016
Trade	6,975	7,262	7,333	7,648	7,407	6,932	6,518	7,347	8,494	9,555	9,628
Utilities	282	293	296	309	299	280	263	297	343	386	389
Personal	2,181	2,271	2,293	2,392	2,317	2,168	2,038	2,298	2,656	2,988	3,011
Total	15,189	15,814	15,969	16,656	16,130	15,095	14,194	16,000	18,496	20,807	20,968

Attachment 6: Air Travel Module

Derivation of Demographic Adjustment Factors

It is expected that the "personal travel" segment of commercial passenger traffic will be more sensitive to air fares than the "business travel" segment. It is also likely that the volume of discretionary travel will be more influenced by public perceptions of airline safety, convenience, and quality of service. One way of quantifying this effect is in a stratified measure of the "propensity to fly" which, in its most rudimentary form, associates with each age group and gender a static value obtained from a survey of travelers.[67] The propensity to fly is considered to be the product of the percentage of a given population segment to have flown in the previous year, and the average number of flights taken by the travelers. This translates into the number of trips per capita associated with that population cohort. These values are subsequently used to modulate forecasts produced by the conventional model as follows:

$$ARPM_T = DI_T \cdot RPM_{D,P,T}$$

where:

$ARPM_T$ = Adjusted personal-travel revenue passenger miles in year t.
DI_T = Demographic index in year t.
$RPM_{D,P,T}$ = Unadjusted forecast of domestic personal RPM in year t.

and:

$$DI_T = \left[\frac{\sum_I POP_{I,T} \cdot PROFLY_{I,T}}{\sum_I POP_{I,T}}\right] \div \left[\frac{\sum_I POP_{I,0} \cdot PROFLY_{I,0}}{\sum_I POP_{I,0}}\right]$$

where:

$POP_{I,T}$ = The population of the I^{th} cohort in year T.
$POP_{I,0}$ = The population of the I^{th} cohort in the base year.
$PROFLY_{I,T}$ = The propensity to fly for the I^{th} cohort.

The following describes the assumptions and data manipulations undertaken to develop age- and gender-specific demographic adjustments to forecasts of personal travel. The use of these factors is predicated on the static nature of the public's propensity to fly ($PROFLY_{I,T} = PROFLY_{I,0}$), absent

[67] This adjustment algorithm has been adapted from that provided in Appendix A of *Forecasting Civil Aviation Activity: Methods and Approaches*, Transportation Research Circular Number 372, Transportation Research Board, June 1991.

sufficient time series data to reflect and predict changing trends.

■ The ATA travel survey provides the percentage of each age group which has flown in the previous year (π_A), as well as the fraction of men and women of all age groups who have flown (π_M, π_W). The first step is to derive an estimate of the percentage of each age group and sex which has flown.

■ Given that N_M and N_W represent the total number of men and women, respectively, the percent of the flying population that are of each gender can be represented as follows:

$$P_M = \frac{\pi_M N_M}{\pi_M N_M + \pi_W N_W} \quad ; \quad P_W = 1 - P_M$$

Using the 1990 Census numbers, $P_M = 0.53$ and $P_W = 0.47$. In other words, 53 percent of people who took at least one air trip in the previous year were male.

■ It is assumed that this gender ratio is constant across age groups and time. This ratio is used to estimate the percentage of the population by gender and age group which has flown in the previous year. The equation for males is as follows:

$$\pi_{M,A} = \frac{P_M \pi_A N_A}{N_{M,A}}$$

In order to determine the number of trips per capita for male and female cohorts, further assumptions are necessary.

■ According to the ATA survey, male travelers flew more than female travelers; the ratio of male to female trips per capita is 1.72, i.e.:

$$\frac{T_M}{N_M} = 1.72 \frac{T_W}{N_W}$$

where T_M and T_W represent the total number of trips by male and female travellers, respectively.

■ In each age group, the number of average trips per capita is reported. It is assumed that the male/female travel ratio holds across age groups, which enables the subsequent division of each figure into two gender-specific figures.

For each age group, the number of trips per capita (TPC) is expressed as:

$$\frac{T_{M,A} + T_{W,A}}{N_{M,A} + N_{W,A}} = TPC_A$$

From above:

$$T_{M,A} = 1.72\left(\frac{T_{W,A}\,N_{M,A}}{N_{W,A}}\right)$$

Substituting, and rearranging:

$$T_{W,A}\left(1 + 1.72\left(\frac{N_{M,A}}{N_{W,A}}\right)\right) = TPC_A\,(N_{M,A} + N_{W,A})$$

which leads to the trips per capita for women, by age group:

$$\frac{T_{W,A}}{N_{W,A}} = TPC_A\left[\frac{N_{M,A} + N_{W,A}}{N_{W,A} + 1.72\,N_{M,A}}\right]$$

The resulting figures are tabulated on the following page.

Table E-72. ATA 1990 Air Travel Survey Data

Age Group	1990 Population ('000)		Percentage Flown		Average Trips per Capita		Propensity to Fly ($PROFLY_{I,T}$)	
	Male	Female	Male	Female	Male	Female	Male	Female
18-24	13,215	12,925	0.31	0.29	3.29	1.91	1.03	0.55
25-34	22,078	21,848	0.37	0.33	4.88	2.83	1.80	0.94
35-44	18,193	19,112	0.38	0.32	5.18	3.03	1.97	0.97
45-54	12,406	13,081	0.39	0.33	4.82	2.81	1.89	0.93
55-64	10,103	11,260	0.33	0.26	4.17	2.45	1.36	0.63
65+	12,853	18,706	0.31	0.19	4.28	2.52	1.34	0.48

Sources:

Population Data: U.S. Department of Commerce, Bureau of the Census, *Projections of the Population of the United States by Age, Sex, and Race: 1988 to 2080,* Population Estimates and Projections, Series P-25, No. 1018.

Percentage Flown & Trips per Capita: ATA, *Air Travel Survey, 1990.*

Attachment 7: Vehicle Emissions Module

Derivation of Emission Factors

INTRODUCTION

This report provides EPA emission factors to be used in the transportation vehicle emission solution algorithm, which is outlined in the *Transportation Sector Component Design Report* (TSCDR) section on emissions. Currently the emissions module is not operable. This algorithm is as follows:

$$EMISS_{IE,IM,IR,T} = EFACT_{IE,IM,IR,T} * U_{IM,IR,T}$$

where *EMISS* is total emissions of pollutant IP by mode IM, in region IR, and time T, *EFACT* is an emission factor based on technology, fuel and vintage weights, and *U* is a measure of annual vehicle activity (vehicle-miles-traveled or fuel consumption in gallons).

The TSCDR specifies modal emission factors for SO_x, NO_x, carbon, CO, CO_2 and VOCs, and calls for emissions to be calculated for the following six transportation modes:

Highway	Non-Highway
Light-Duty Vehicles	Rail
Freight Trucks	Air
Buses	Water

A number of these transportation modes have subcomponent modes that are to be handled in a separate TERF "Miscellaneous End-Use Component" module. These subcomponent modes include military aircraft, recreational boating, passenger rail, and buses. This report also provides the emission factors for these miscellaneous transportation energy end-use categories, as well as for alternative fuel vehicles (AFVs).

Pollutant emission factors are not reported for certain transportation vehicles. Reasons for the exclusion of these emission factors include one or more of the following:

- the lack of adequate EPA emissions testing results for the production of reliable fleet-average emission rates,

- the quantities of a pollutant generated a vehicle type are not significant,

- the pollutant is not regulated by the EPA (for example, only aircraft HC and smoke emissions are currently regulated).

Such instances of nonreported emission factors are documented in the relevant transportation mode sections of this report.

HIGHWAY MOBILE SOURCE EMISSION FACTORS

Highway Source Emission Factor Information Sources

Emission factors and the accompanying calculation procedures used for virtually all federal and state mobile source emission inventory studies come from the following EPA source documents:

- *Compilation of Air Pollutant Emission Factors - Volume II: Mobile Sources* (AP-42, Fourth Edition, September 1985)

- *Supplement A to AP-42 Volume II*, January 1991.

- *User's Guide to MOBILE4.1*, EPA-AA-TEB-91-01 (EPA Office of Mobile Sources, Emission Control Technology Division, July 1991).

- *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachments A through J (This EPA memorandum supersedes the mobile source emission inventory preparation instructions contained in *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, which is currently being revised)

- *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, EPA-450/4-81-26d (revised), (July 1992).

The document, *Compilation of Air Pollutant Emission Factors - Volume II*, reports all data and emission factor calculation algorithms for both highway and off-highway emission sources.

Supplement A to AP-42 presents updated emissions factor information for highway sources based on the results of additional vehicle test data obtained subsequent to the publication of the original AP-42 Air Pollutant Emission Factor compilation document, as well as methodological modifications reflecting calculation refinements and new emission regulations. Both EPA data source documents categorize highway mobile sources into eight types: light-duty gasoline vehicles (LDGVs), light-duty gasoline-powered trucks with a gross vehicle weight rating of less than or equal to 6,000 lbs (LDGT1s), light-duty gasoline-powered trucks with a gross vehicle weight rating greater than 6,000 lbs (LDGT2s), heavy-duty gasoline-powered vehicles (HDGVs), light-duty diesel-powered vehicles (LDDVs), light-duty diesel-powered trucks (LDDTs), heavy-duty diesel-powered vehicles (HDDVs), and motorcycles. The EPA document, *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, provides the most up-to-date instructions for all state and local agencies involved in the preparation of mobile source inventories. The EPA makes frequent mention of the fact that a number of emission rate studies are ongoing. Therefore, frequent monitoring of the status of EPA analytical studies is suggested in order to ensure that TERF emission factors reflect the latest available emission testing and methodological information.

Highway mobile source emission factor calculation routines, outlined in the above EPA documents, are incorporated into EPA's MOBILE model, which estimates hydrocarbon, carbon monoxide, and oxides of nitrogen emission factors for gasoline and diesel-powered vehicles. The most recent version of the mobile emissions model, MOBILE4.1, was released in 1991 for the express purpose of preparing all 1990 base year emission inventories mandated by the CAAA for all areas exclusive of California, and to prepare CAAA-mandated carbon monoxide emissions inventory projections. However, MOBILE4.1 does not incorporate the effects of other CAAA provisions, such as the Tier I exhaust emissions standards for light-duty vehicles and light-duty trucks. Revisions to the MOBILE4.1 model to reflect CAAA provisions for NMHC and NO_x and additional test data are being discussed and planned for incorporation into the new MOBILE5 model. The EPA is currently seeking recommendations through a series of public workshops, and expects to release MOBILE5 in the fall of 1992. Appendix E.EM.B provides an excerpt from an EPA letter handout (dated March 5, 1992) that outlines potential MOBILE5 revisions.

Highway source emission factors for California are calculated through the use of the California Air Resources Board's own emission factor model, EMFAC. The most recent version of this model is EMFAC7EP, which incorporates the most recent California vehicle and fuel standards. All EMFAC model versions are variants of EPA's MOBILE model, and have been customized to serve the emission calculation needs of the CARB. EPA's Office of Mobile Sources is currently examining CARB in-use test data for vehicles certified to meet California's 0.7 gpm NO_x emission standard. Emission rate equations for reflecting the effects of California's low-emitting vehicle (LEV) program and inspection/maintenance credits are also being considered for inclusion in MOBILE model updates.

The California Air Resources Board uses a separate computer model to assimilate emission test data and calculate basic emission rates. This model, CALIFAC, uses the CARB's In-Use Surveillance Program and the Inspection/Maintenance Project databases (along with EPA data) to derive the basic emission factors. The basic emission factors serve as the inputs to EMFAC, which subsequently applies emission correction factors to produce final emission factors. This report lists the California highway emission factors along with the EPA national emission factors.

The EPA Procedure for Calculating Mobile Source Emissions Factors

Methodology Overview

Federal and state agency-developed emission factors for each vehicle type are derived from a four-step process[68]:

> First, "basic exhaust emission factors", or BEFs, are estimated according to rigid federal testing procedures[69].
>
> Second, the BEFs are adjusted with a series of multiplicative and additive correction factors that account for testing condition variances in ambient temperature and operating mode, as well as expected emission contxl device tampering rates.
>
> Third, the BEFs are further adjusted with a composite correction factor that reflects actual vehicle characteristics and driver operating practices (For the hydrocarbon BEF, separate emission factors for evaporative and running losses are added. In addition, the hydrocarbon and carbon monoxide BEFs are adjusted for fuel volatility.). A number of these correction factors are not included in the emission factor calculations for diesel-powered vehicles and trucks due primarily to a lack of reliable data.
>
> Fourth, consolidated BEFs are derived by weighting the adjusted BEFs according to the fraction of total miles driven for each model year, and then summing over the 25 historical

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[68] All emission rate equations and data referenced in this section come from EPA's AP-42 document and accompanying supplements, or the MOBILE4.1 model documentation, unless otherwise noted.

[69] Exhaust and evaporative emissions testing procedures for light-duty gasoline and diesel-powered vehicles are stipulated in the Code of Federal Regulations, 40 CFR Part 86, Subpart B, July 1, 1989. Testing procedures for heavy-duty gasoline and diesel-powered vehicles are stipulated in 40 CFR Part 86, Subpart N, July 1, 1989.

model years that constitute the in-use vehicle fleet for each calendar year.[70] The equations for the consolidated emission factors are as follows:

$$EFHC = \Sigma\, TF * [(ADJBEF * SALHCF * RVPCF) + REFUEL + RNGLOS + CCEVRT]$$
$$EFCO = \Sigma\, TF * (ADJBEF * SALHCF * RVPCF)$$
$$EFNO_x = \Sigma\, TF * (ADJBEF * SALHCF)$$

where:

ADJBEF =	Adjusted basic exhaust emission factor in grams per mile,
SALHCF =	Composite speed, air conditioning, extra load, and trailer towing correction factor,
RVPCF =	Fuel volatility correction factor,
REFUEL =	Refueling hydrocarbon emission factor (g/mile),
RNGLOS =	Running loss hydrocarbon emission factor (g/mile),
CCERVT =	Crankcase and evaporative hydrocarbon emission factor (g/mile),
TF =	Fraction of total miles driven

(Summation occurs over 25 model years *i*, from n-24 to n, where *n* is the calendar year)

Methodology Details

Federal Test Procedures. The federal test procedures calculate basic exhaust and evaporative emissions for each vehicle model under specified ambient temperature and humidity levels, average speed and idle time, vehicle-miles-traveled (VMT), percent of VMT in cold-start, hot-start, and stabilized operations, trip length, and fuel volatility.[71] The gathering of exhaust emissions data is accomplished with three test segments. For Segment No. 1 (cold-start test), emissions for the first 505 seconds after engine start-up are collected. For Segment No. 2 (stabilized test), emissions are collected for the next 870 seconds. Finally, for Segment No. 3 (hot-start test), the engine is turned off for a ten-minute duration, and is restarted and run for an additional 505 seconds with emissions being collected. The EPA conducts the test cycles at both low and high altitude locations.

Basic Emission Rates. The basic emission rate is calculated by a two-step formula based on the assumption that emission rates increase linearly with respect to accumulated vehicle mileage. First,

[70] The number of model years for the in-use fleet was expanded from 20 to 25 with the release of MOBILE4.1 (see User's Guide to MOBILE4.1, Sec. 1.1.4.).

[71] The measure of volatility is *Reid Vapor Pressure*. Vapor pressure measures the level of surface pressure in pounds per square inch (psi) required to keep a liquid from vaporizing. Vehicles are tested at a certified RVP of 9.0 psi.

a zero-mile emission level is obtained from the in-use vehicle testing results for a specific model year and pollutant. Added to this basic emission rate is an adjustment that reflects the culmulative mileage for the model year vehicle and a per-10,000 mile emission deterioration rate. The two step formula accounts for vehicles with cumulative mileage of less than 50,000, and vehicles with mileage in excess of 50,000. The following example shows the equations and calculations used to obtain basic carbon monoxide emission rates for light-duty vehicles with a 1990 model year.

Example 1: Calculating Carbon Monoxide Base Emission Rates

<u>BER Two-Step Formula</u>

$$BER = ZML + (DR1 * M), \quad \text{for } M \leq 50{,}000 \text{ Miles}$$
$$= ZML + (DR1 * 5) + (DR2 * (M - 5), \quad \text{for } M \leq 50{,}000 \text{ Miles}$$

where

ZML =	Zero-mile emission level in gpm
DR1 =	Emission deterioration rate for vehicles with less than or equal to 50,000 miles, in gpm per 10,000 miles
DR2 =	Emission deterioration rate for vehicles with more than 50,000 miles, in gpm per 10,000 miles
M =	Model year cumulative mileage divided by 10,000 miles

<u>Assumptions:</u>

(1) CO emissions are for light-duty gasoline-powered vehicles with a 1990 model year
(2) Tests conducted at low altitude
(3) Calculate emission levels at cumulative mileage intervals of 50,000 and 100,000 miles.

<u>50,000 Mile Emission Level:</u>

$$BER = 2.813 + (0.769 * 5) = 6.658 \text{ grams per mile CO}$$

<u>100,000 Mile Emission Level:</u>

$$BER = 2.813 + (0.769 * 5) + (0.961 * (10 - 5)) = 11.463 \text{ grams per mile CO}$$

Data Source: U.S. Environmental Protection Agency Office of Mobile Sources, *Supplement A, Compilation of Air Pollutant Emission Factors, Volume II - Mobile Sources* (AP-42), January 1991.

Basic Emission Factor Adjustments. The basic emission factors are adjusted with a series of general and pollutant-specific correction factors to account for ambient and vehicle operation characteristics that differ from the standardized federal testing conditions. The adjusted BER equations are as follows:

$$ADJBEF_{HC} = \{[(BER * OMTCF) - OFFMTH] * PCLEFT\} + OMTTAM$$

$$ADJBEF_{CO} = (BER * OMTCF * PCLEFT) + OFFCO + OMTTAM$$
$$ADJBEF_{NOx} = (BER * OMTCF) + OMTTAM$$

The equation terms are described below:

Temperature/Operating-Mode Correction Factor (OMTCF) — This multiplicative correction factor accounts for the observation that vehicles produce a smaller quantity of emissions as they move from cold-start to stabilized and hot-start operating modes. The OMTCF is expressed as a sum of VMT-weighted linear functions of the fleet cumulative mileage for each model year, adjusted for (1) the emissions contribution attributable to each operating mode (represented as intercept and slope coefficients of the linear functions), and (2) a previously estimated temperature correction factor for each model year, pollutant, test segment, and ambient temperature (not applicable to diesel-powered vehicles and trucks). As with the basic emission rate formula, OMTCFs are calculated with a two-stage formula to reflect emissions deterioration for vehicles with cumulative mileage greater than 50,000 miles:

$$OMTCF = (TERM1 + TERM2 + TERM3) / DENOM$$

	Cumulative Mileage $\leq$ 50,000	Cumulative Mileage > 50,000
TERM1 =	$W * TCF_1 * [B_1 + (D_{11} * M)]$	$W * TCF_1 * [B_1 + (D_{11} * 5)] + [D_{12} * (M - 5)]$
TERM2 =	$(1-W-X) * TCF_2 * [B_2 + (D_{21} * M)]$	$(1-W-X) * TCF_2 * [B_2 + (D_{21} * 5)] + [D_{22} * (M - 5)]$
TERM3 =	$X * TCF_3 * [B_3 + (D_{31} * M)]$	$W * TCF_3 * [B_3 + (D_{31} * 5)] + [D_{32} * (M - 5)]$
DENOM =	$B_0 + (D_{01} * M)$	$B_0 + (D_{01} * 5) + [D_{02} * (M - 5)]$

where:

W =	fraction of vehicle-miles-traveled in the cold start mode
X =	fraction of vehicle-miles-traveled in the hot start mode
TCF_i =	high or low temperature correction factor (depending on ambient testing temperature) for pollutant, model year, and test segment "i"
B_i =	normalized intercept coefficient for pollutant, model year, and test segment "i"
D_{ij} =	normalized slope coefficient for pollutant, model year, test segment "i" and culmulative mileage level "j" (1 if $M \leq 5$; 2 if $M > 5$)
M =	cumulative mileage divided by 10,000 miles for each model year

The low temperature correction factor is applied when the ambient temperature is lower than the reference test temperature of 75°F. For all pollutants, test segments, and model years, *except* segment 1 (cold start) CO emissions for model years from 1980 and later, a simple exponential model is used.[72] In the case of cold start carbon monoxide OMTCFs for model years 1980 and later, two additional calculation steps are necessary. First, TCF_1 is removed from the TERM1 equation in order to eliminate the temperature correction related to the cold start mode. Second, an alternative additive version of the low temperature correction factor is calculated, the "CO offset" (**OFFCO**), which adjusts the cold start emissions for higher CO produced during the cold start mode. The CO offset is multiplied by the percent of VMT in the cold start mode (the "W" term) and adjusted for fuel volatility if the temperature is greater than 40°F. The CO offset term is then added to the basic CO exhaust emission rate factor.

The high temperature correction factor equation for pre-1980 model years, applied when the ambient temperature is higher than 75°F, is similar to that of the low temperature correction factor. For post-1979 model years, an alternative correction factor is used that incorporates a fuel volatility correction component. The combined high temperature/fuel volatility correction factor model is:

$$TRCF = e^{\{[A * (RVP - 9.0)] + [B * (T - 75.0)] + [C * (RVP - 9.0)] * (T - 75.0)\}}$$

where RVP is the fuel volatility level in psi RVP, T is the ambient temperature, and A, B, and C are estimated coefficients.

Tampering Offset (TAMPOFF) — A tampering and misfueling offset (in grams per mile) is added to the basic emission rate to reflect the assumption that a certain fraction of flHxt vehicles have had emission control components disabled or fueling components damaged. Such tampering and misfueling occurrences increase exhaust and evaporative emissions. Tampering/misfueling types tracked by the EPA include air pump disablement, catalyst removal, EGR system disablement, filler neck damage, fuel tank misfueled, combined filler neck damage and fuel tank misfueled, PCV system disablement, canister disconnection, and combined canister and fuel cap removal.

The EPA has conducted nationwide tampering/misfueling surveys since 1978, and data for surveys completed in 1984, 1985, and 1986 have been incorporated into the Tampering Offset calculation methodology.[73] The TAMPOFF is applied to only four vehicle types due

[72] The equation is: $TCF_{low} = EXP\ [TC_{ibp} * (T - 75.0)]$, where TC_{ibp} is a coefficient for model year *i*, pollutant *p*, and test segment *b*, at the ambient reference temperature of 75 degrees Fahrenheit; and T is the ambient temperature.

[73] Source: *Compilation of Air Pollutant Emission Factors, Volume 2 — Mobile Sources, Supplement A*, Appendix E, p. E-1. Additional survey results gathered after the publication of this document are also included in the offset estimation equations.

to the lack of comprehensive data: light-duty gas-powered vehicles, light-duty gas-powered trucks (both weight categories I and II), and heavy-duty gas-powered vehicles. The TAMPOFFs for each tampering type are calculated with the following equation for calendar year $_n$:

$$TAMPOFF = TAMP_{ipm} * PEQUIP_{im} * RATE_{im}$$

where:

$TAMP_{ipm}$ =	incremental increase in emissions from tampered vehicles for model year *i*, pollutant *p*, and tampering type *m*,
$PEQUIP_{im}$ =	percent of the model-year *i* vehicles that are equipped with item *m* that can be tampered,
$RATE_{im}$ =	percent of model-year *i* vehicles with equipment *m* that has been tampered with.

The term, TAMP, is derived from linear regression equations with cumulative mileage in 10,000-mile increments serving as the regressor or explanatory variable (the regression intercept is interpreted as the zero-mileage emission rate). The regressions yield deterioration rates up to 50,000 cumulative mileage, with mileage in the 50,000 to 130,000 range handled with an additional adjustment factor representing each tampering-type/vehicle-type combination.

The tampering-type emissions offsets are combined to form an overall composite offset with each tampering-type offset adjusted with the applicable temperature correction factor (TCF), and weighted according to the percent of accumulated vehicle-miles-traveled in cold start, stabilized, and hot start modes. The tampering offset is not applicable to diesel-powered vehicles and trucks.

Inspection and Maintenance (I/M) Program Exhaust Emission Benefit (PCLEFT) — This optional emissions rate adjustment factor accounts for the hydrocarbon and CO emissions reduction benefits attributable to inspection/maintenance programs. The emission rate I/M credits are estimated using a separate EPA model, TECH IV+, which is currently being updated into a TECH 5 version that will include a NO_x benefit submodel and other revisions reflecting new I/M program data.[74] I/M program parameters for the TECH model

[74] The only NO_x reduction benefit currently modeled is from a reduction in tampering rates resulting from I/M programs. EPA analysis of transient I/M test (IM240) data indicates that additional emissions reductions result from NO_x cutpoint I/M programs. (See Appendix E.EM.C, List of Potential Revisions for MOBILE5, Item No. 3-5.)

include program start year, stringency level, first/last model years of vehicle subject to program requirements, waiver rates, compliance rates, program type, inspection frequency, vehicle type, test type, and availability of alternative I/M credits for certain technology groups. The I/M program emissions benefit is not applicable to diesel-powered vehicles and all truck types.

Methane Offset (OFFMTH) — This grams-per-mile offset is used to adjust the hydrocarbon basic emission rate when nonmethane HC emissions are estimated. Model-year offsets are calculated for each of the three test segments.

The BEFs are further adjusted by a *composite speed, air conditioning, extra load, and trailer towing correction factor* (**SALHCF**), with the following form:

$$SALHCF_{HC,CO} = SCF * ACCF * XLCF * TWCF$$

and

$$SALHCF_{NOx} = SCF * ACCF * XLCF * TWCF * HCF$$

Each of the equation terms are described below.

Speed Correction Factor (SCF) — Federal test procedures call for the collection of basic exhaust emissions at an average speed of 19.6 miles per hour. To account for higher and lower average speeds exhibited by in-use vehicles, correction factors for three speed ranges were calculated using linear regression.[75] The ranges are low speeds (2.5 to 19.6 mph), moderate speeds (19.6 to 48 mph), and high speeds (48 to 65 mph). The speed correction factors are delineated by model year group, technology, pollutant, and emission level (i.e., normal vs high emitters), but are weighted and combined into one basic speed correction factor applied to base emission rates.

Air Conditioning Correction Factor (ACCF) — The air conditioning correction accounts for the impact of air conditioner operations on pollutant emission types at various ambient temperatures for each model year (This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles). The correction factor is expressed as a linear relationship to temperature, adjusted with a multiplicative factor that reflects the fraction of AC units in use. The air conditioning correction factor equation has the following form:

[75] The speed correction factors are normalized to the speed associated with a weighted sum of the cold start and hot start mode VMT fractions. The SCFs were derived from multiplicative linear regression equations.

$$ACCF = V * U * [A + (B * (T - 75) - 1)] + 1$$

where:

V =	fraction of vehicles equipped with AC,
U =	faction of AC units in use = (DI - 70)/10, where DI is the temperature discomfort index,
DI =	((DB + WB)*0.4) + 15,
DB =	dry bulb temperature,
WB =	wet bulb temperature,
A =	intercept coefficient,
B =	slope coefficient,
T =	ambient temperature.

Extra Load Correction Factor (XLCF) — This correction factor incorporates the impacts on emissions of an increase of 500 pounds to the test standard vehicle weight, which includes a driver and one passenger. (This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles). The extra load correction factor equation is:

$$XLCF = [(XLC - 1.0) * U] + 1.0$$

where XLC is a factor coefficient for each model year and pollutant,[76] and U is the fraction of vehicle-miles-traveled with the extra load.

Trailer Towing Correction Factor (TWCF) — The trailer towing correction factor, which accounts for the effect on emissions of an extra trailer weight of 1,000 pounds, is calculated with an equation that is identical in structure to that used for calculating the extra load correction factor:

$$TTCF = [(TTC - 1.0) * U] + 1.0$$

where TTC is a factor coefficient for each model year and pollutant,[77] and U is the fraction of vehicle-miles-traveled with the extra trailer load.

This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered

[76] For example, XLC varies from 1.0786 to 1.0455 for low altitude light-duty gas-powered vehicles, depending on the model year. The XLC range for CO is 1.3058 to 1.1347, and the range for NO_x is 1.0719 to 0.9535.

[77] For example, TTC varies from 1.7288 to 1.2614 for low altitude light-duty gas-powered vehicles, depending on the model year. The TTC range for CO is 1.8940 to 3.9722, and the range for NO_x is 1.1184 to 1.3875.

vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles.

NO_x Humidity Correction Factor (HCF) — NO_x emission factors are normalized to 75 grains of water per pound of dry air. To achieve this normalization given various humidity levels, a multiplicative correction factor is applied to the composite NO_x SALHCF. The following HCF equation is applicable for all model years:

$$HCF = 1.0 - 0.0038 * (H - 75.0)$$

where H = humidity level in grains of water/lb. dry air. This humidity correction factor is not applicable to heavy-duty diesel-powered trucks.

Data obtained from monitoring emissions at different Reid Vapor Pressure levels shows that hydrocarbon and CO emissions increase as volatility increases. For exhaust emissions at fuel volatility levels different from the test certification RVP of 9.0 psi, and when the ambient temperature is greater than 40°F, a *fuel volatility correction factor* (**RVPCF**) is applied to the basic hydrocarbon and CO emission factors.

There are three fuel volatility correction factor equations, with the selection based on vehicle model year and ambient temperature. For model years 1971 through 1979 (and at all temperatures), the RVPCFs for hydrocarbons and CO are based on a simple linear extrapolation model[78]:

$$RVPCF_{HC} = (0.56222 + 0.012512 * RVP) / 0.67483$$
$$RVPCF_{CO} = (7.1656 + 0.33413 * RVP) / 10.17277$$

For post-1979 model years and at a temperature greater than 75°F, the RVPCF is incorporated with the high temperature correction factor discussed in the Temperature/Operating-Mode Correction Factor (OMTCF) section.

For post-1979 model years and at a temperature in the 40°F to 75°F range, a two-step correction procedure is used. First, a RVP correction factor evaluated at 75°F is obtained using the combined high temperature/fuel volatility model. The resulting RVPCF is then used as an input to the following equation:

$$RVPCF = = 1.0 + \{[(RVPCF_{75^\circ F} - 1.0) * [(T - 40.0) / 35.0)]\}$$

[78] The denominator value represents the numerator evaluated at the certification Reid Vapor Pressure of 9 psi.

where T is the ambient temperature in the range of 40°F to 75°F.

The post-1979 model year fuel volatility correction factors are also disaggregated based on test segment and fuel delivery system (carbureted, throttle-body fuel injection, and multi-point fuel injection).

Evaporative Emissions Factors. In addition to the basic exhaust emission factors for hydrocarbons, evaporative emissions from carburetion and fuel tank systems must be included in the consolidated hydrocarbon emission factors. The EPA models five types of HC evaporative emissions: *crankcase*, *hot soak* (evaporative emissions occurring after a trip), *diurnal* (release of fuel vapors due to an expansion of the air-fuel mixture in a partially filled fuel tank when the ambient temperature increases), *running loss* (emission generated during vehicle operation), and *refueling* (displacement of fuel vapor from the tank during refueling, and spillage). Evaporative emission factors are not applicable to diesel-powered vehicles and trucks.

Crankcase, hot soak, and diurnal emissions (CCERVT) are calculated with one equation:

$$CCERVT = [(HS + TAMPHS) * TPD_j] + [(DI + TAMPDI) / MPD_j] + (CC + TAMPCC)$$

where:

HS =	Hot soak emission rates in grams per trip, corrected for temperature and RVP fuel volatility,
TAMPHS =	Excess hot soak emission rates due to tampering, corrected for RVP fuel volatility,
TPD_j =	Trips per day for age *j* vehicles,
DI =	Diurnal emission rates in grams, corrected for temperature and fuel volatility,
TAMPDI =	Excess diurnal emission rates due to tampering, corrected for temperature and RVP fuel volatility,
MPD_j =	Miles-per-day values for age *j* vehicles,
CC =	Crankcase emissions in grams per mile,
TAMPCC =	Excess crankcase emissions due to tampering.

Running loss emissions (RNGLOS) are calculated in a similar manner: loss emission rates in grams per mile are corrected for temperature and RVP fuel volatility (RULOSS), and then are added to the excess running loss emissions ascribed to tampering (TAMPRL).

Refueling loss emissions (REFUEL) are calculated by adding together the displacement fueling losses corrected for RVP fuel volatility (DISP) and an average spillage rate (SPILL), both measured in grams per gallon. This figure is divided by the road fuel economy rate (ROADFE), measured in gallons per mile.

All evaporative emission factor components are modeled as a function of the ambient temperature and fuel volatility. Running losses are modeled with two additional variables — average speed and trip duration. Refueling losses are modeled with one additional variable, defined as the temperature difference between the dispensed fuel and the residual tank fuel. EPA has also recently incorporated into its modeling the results of inspection/maintenance program testing for fuel/evaporative control system leaks and the capability of the carbon canister to properly purge vapors. The impact of "pressure and purge" problems on hot soak, diurnal, and running loss emission rates are reflected in MOBILE4.1.[79]

Calculation of Travel Weighting Fractions. After emission factor corrections have been applied to the basic exhaust emission factors, and hydrocarbon evaporative and exhaust emission factor components have been added together, travel weighting fractions (TFs) are applied for deriving the final consolidated emission factors.

The TFs represent model-year proportions of total vehicle-miles-traveled for each vehicle type. They are calculated with the use of an annual mileage accumulation rate distribution, a registration distribution[80], and a diesel sales distribution (applicable to all vehicle types *except* heavy-duty gas-powered vehicles and heavy-duty gas-powered trucks).

Example 2 shows the calculation of a consolidated hydrocarbon emission factor for model-year 1988 light-duty gasoline-powered vehicles.

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[79] User's Guide to MOBILE4.1, Sec. 1.1.6, p. 1-12.

[80] The EPA collects July 1 registration data, which is adjusted to reflect registration activity as of January 1. Vehicle sales are assumed to be uniform throughout the year.

Example 2: Calculating a Consolidated Hydrocarbon Emission Factor for Light-Duty Gasoline Powered Vehicles

Assumptions:

(1) HC emissions are for light-duty gasoline-powered vehicles with a 1988 evaluation calendar year, 20-model-year vehicle window, with testing conducted at low altitude.
(2) Daily minimum and maximum ambient temperatures are 60°F and 80°F, respectively.
(3) All conditions match the basic federal test conditions (i.e., air conditioning, extra load, trailer towing, humidity levels, and other basic exhaust emission correction factors have no affect on the calculations, and are therefore set to 1.0).
(4) No inspection/maintenance or anti-tampering programs are assumed.
(5) Certification fuel volatility of 9.0 psi is assumed.
(6) Total HC emissions are calculated at an average speed of 30 miles per hour.
(7) Percentages of vehicle-miles-traveled in the cold start, stabilized, and hot start operating modes are 40%, 30%, and 30%, respectively.
(8) Basic HC emission factors are adjusted for the effects of tampering.
(9) Methane is included in HC calculations.

Consolidated Emission Factor Equation

$$CONBEFHC_n = \sum TF_i * [(BEF * SALHCF) + REFUEL + RNGLOS + CCEVERT]$$

where:

$CONBEFHC_n$= Consolidated Hydrocarbon Emission Factor for calendar year *n*,
TF_i= Travel Weighting Fraction for Model Year *i*,
BEF= Adjusted Hydrocarbon Exhaust Emission Factor,
SALHCF= Speed Correction Factor,
REFUEL= Refueling HC Emission Factor,
RNGLOS= Running Loss HC Emission Factor,
CCEVERT= Crankcase and Evaporative HC Emission Factor.

Data Table

Model Year (i)	TF	BEF (gpm)	SALHCF (gpm)	REFUEL (gpm)	RNGLOS (gpm)	CCEVERT (gpm)	$CONBEFHC_n$: TF*(BEF*SALHCF)+ REFUEL+RNGLOS+C CEVERT
1988*	0.0307	0.415	0.730	0.243	0.254	0.147	0.029
1987	0.1209	0.472	0.730	0.244	0.254	0.155	0.121
1986	0.1102	0.577	0.730	0.248	0.264	0.177	0.122
1985	0.0985	0.688	0.730	0.255	0.275	0.215	0.123
1984	0.0879	0.808	0.730	0.262	0.285	0.258	0.123
1983	0.0783	0.938	0.730	0.266	0.294	0.300	0.121
1982	0.0679	1.257	0.730	0.263	0.303	0.345	0.124
1981	0.0598	1.480	0.730	0.272	0.311	0.390	0.123
1980	0.0537	2.507	0.730	0.291	0.551	0.576	0.174
1979	0.0481	4.941	0.730	0.335	0.559	0.620	0.246
1978	0.0427	5.253	0.730	0.339	0.566	0.665	0.231
1977	0.0381	5.505	0.730	0.370	0.650	1.515	0.250
1976	0.0328	5.807	0.717	0.387	0.656	1.593	0.223
1975	0.0280	6.043	0.717	0.427	0.662	1.674	0.199
1974	0.0237	5.844	0.706	0.473	0.668	1.759	0.167
1973	0.0197	5.945	0.706	0.473	0.673	1.846	0.142
1972	0.0167	5.906	0.795	0.465	0.679	1.937	0.130
1971	0.0134	9.089	0.798	0.469	0.683	2.726	0.149
1970	0.0104	9.296	0.811	0.451	0.715	3.556	0.128
1969	0.0185	8.856	0.781	0.454	0.684	3.660	0.217

$$\sum_{=N-1}^{N} = \mathbf{3.142}$$

Data Source: U.S. Environmental Protection Agency Office of Mobile Sources, *Supplement A, Compilation of Air Pollutant Emission Factors, Volume II - Mobile Sources* (AP-42), January 1991, Appendix G.

Highway Mobile Source Emissions Factor Methodology

Carbon Monoxide, Volatile Organic Compound, and Nitrogen Oxide Emission Factors: Conventional Vehicles

DAC calculated VOC, CO, and NO_x emission factors for highway sources using a two-step methodology. First, MOBILE4.1 model runs were conducted to obtain baseline emission factor forecasts. Second, off-line adjustments to the baseline emission factor forecasts were made to reflect the new CAAA regulations that have not been incorporated into the MOBILE4.1 solution algorithms. Table E-80 provides the adjusted MOBILE4.1 emission factors for conventional vehicle types.[81] The vehicle types consist of LDGVs, LDGTs (combined Class 1 and 2), HDGVs, LDDVs, LDDTs, and HDDVs. Table E-81 provides the EPA definitions for each of the vehicle-type categories.

Emission factors for heavy-duty diesel-powered vehicles (HDDVs) should be used for diesel-powered buses. This is recommended by the EPA, which cites the similarities between the two vehicles types as well as the lack of comprehensive emission testing for buses (note that the EPA bus emission factors are reported in grams per mile as opposed to the TERF lbs./1,000 gal. specification). Efforts at improving the EPA bus emission data base are ongoing because of concern that the HDDV emission factors do not accurately reflect in-use characteristics of buses in urban areas.

A complication results in trying to combine the EPA vehicle-type emission factors into the freight truck category designated in the TSCDR. As shown in Table E-81, the EPA vehicle-type categories for heavy-duty vehicles and trucks do not correspond to the weight categories used by either the TIUS or the FHWA Highway statistics report. The EPA uses a weight cut-off of 8,500 pounds GVW for its heavy-duty classifications. Trucks with an average weight greater than 10,000 pounds are classified as medium, light-heavy, or heavy-heavy by the TIUS. There is no weighting method that proves satisfactory for normalizing the EPA emission factors to the FHWA weight categories. Therefore, we recommend that the EPA emission factors for gasoline and diesel heavy-duty vehicles (HDGVs and HDDVs) be used as the TERF freight truck emission factors.

[81] Five-year interval forecasts were interpolated to produce year-to-year emission factors.

Table E-73. Adjusted MOBILE4.1 Emission Factors

YEAR	LDGV			LDGT			HDGV		
	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx
1990	2.09	20.63	1.43	4.20	29.16	1.93	10.84	101.36	5.82
1991	2.33	18.67	1.16	3.84	26.16	1.81	9.90	90.91	5.61
1992	2.59	16.89	0.94	3.51	23.47	1.70	9.05	81.53	5.41
1993	2.89	15.28	0.76	3.21	21.06	1.59	8.27	73.12	5.21
1994	3.22	13.83	0.62	2.93	18.89	1.49	7.55	65.58	5.02
1995	3.59	12.51	0.50	2.68	16.95	1.40	6.90	58.82	4.84
1996	2.98	11.88	0.50	2.54	15.72	1.35	6.45	52.74	4.73
1997	2.47	11.29	0.50	2.41	14.58	1.29	6.04	47.28	4.63
1998	2.05	10.72	0.50	2.28	13.53	1.24	5.65	42.39	4.53
1999	1.70	10.18	0.50	2.16	12.55	1.20	5.28	38.01	4.43
2000	1.41	9.67	0.50	2.05	11.64	1.15	4.94	34.08	4.33
2001	1.34	9.27	0.50	1.96	11.01	1.13	4.66	31.50	4.29
2002	1.27	8.88	0.50	1.87	10.41	1.10	4.40	29.11	4.26
2003	1.21	8.51	0.50	1.79	9.85	1.08	4.15	26.90	4.22
2004	1.15	8.15	0.50	1.71	9.31	1.06	3.92	24.86	4.19
2005	1.09	7.81	0.50	1.63	8.81	1.04	3.70	22.98	4.15
2006	1.09	7.78	0.50	1.62	8.75	1.04	3.66	22.33	4.13
2007	1.09	7.76	0.50	1.62	8.69	1.03	3.61	21.71	4.11
2008	1.08	7.73	0.50	1.61	8.63	1.03	3.57	21.10	4.10
2009	1.08	7.71	0.50	1.61	8.58	1.02	3.53	20.51	4.08
2010	1.08	7.68	0.50	1.60	8.52	1.02	3.49	19.93	4.06
2011	1.08	7.67	0.50	1.60	8.52	1.02	3.49	19.87	4.05
2012	1.08	7.67	0.50	1.60	8.52	1.02	3.49	19.81	4.04
2013	1.08	7.66	0.50	1.60	8.52	1.01	3.48	19.76	4.04
2014	1.08	7.66	0.50	1.60	8.52	1.01	3.48	19.70	4.03
2015	1.08	7.65	0.50	1.60	8.52	1.01	3.48	19.64	4.02
2016	1.08	7.65	0.50	1.60	8.52	1.01	3.48	19.64	4.02
2017	1.08	7.65	0.50	1.60	8.51	1.01	3.48	19.64	4.02
2018	1.08	7.65	0.50	1.60	8.51	1.01	3.48	19.63	4.02
2019	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2020	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2025	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2030	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02

Adjustment notation:

(1) LDGV's: Adjust VOC downward by 0.14 gpm for 1995 through 2030 to reflect decrease in exhause emission standard from 0.39 gpm to 0.25 gpm.

(2) LDGV'S: Assume NO_x emissions of 0.50 gpm beginning in 1995 and forward to reflect new/in-use standard fo 0.40 gpm and 0.6 gpm 100,000-mile certification standard.

(3) LDGV's: CO emission factors include new cold temperature standards.

(4) LDDV's: MOBILE4.1 emission factors are below standards; therefore no adjustments to LDDV emission factors are necessary.

(5) HDDV's: MOBILE4.1 incorporates 1994 HC and CO standards. NO_x standard was lowered, but MOBILE4.1 produces forcast emission factors at about the same level as the standards.

Table E-73 (Continued)

YEAR	LDDV			LDDT			HDDV		
	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx
1990	0.71	1.67	1.63	0.96	1.90	1.87	2.84	13.03	19.45
1991	0.72	1.68	1.63	0.97	1.91	1.86	2.73	12.75	17.72
1992	0.73	1.70	1.64	0.98	1.91	1.85	2.62	12.49	16.14
1993	0.74	1.71	1.64	1.00	1.92	1.85	2.52	12.22	14.70
1994	0.75	1.73	1.65	1.01	1.92	1.84	2.42	11.96	13.39
1995	0.76	1.74	1.65	1.02	1.93	1.83	2.32	11.71	12.20
1996	0.74	1.71	1.59	0.98	1.89	1.76	2.28	11.61	11.56
1997	0.71	1.68	1.53	0.94	1.85	1.69	2.25	11.51	10.94
1998	0.69	1.65	1.48	0.91	1.81	1.62	2.22	11.41	10.37
1999	0.67	1.63	1.42	0.87	1.78	1.56	2.18	11.31	9.82
2000	0.65	1.60	1.37	0.84	1.74	1.50	2.15	11.21	9.30
2001	0.62	1.57	1.32	0.80	1.70	1.44	2.14	11.18	9.11
2002	0.59	1.53	1.27	0.76	1.66	1.39	2.13	11.16	8.92
2003	0.57	1.50	1.22	0.73	1.62	1.33	2.13	11.13	8.73
2004	0.54	1.47	1.17	0.69	1.59	1.28	2.12	11.11	8.55
2005	0.52	1.44	1.13	0.66	1.55	1.23	2.11	11.08	8.37
2006	0.52	1.44	1.12	0.66	1.55	1.22	2.11	11.07	8.32
2007	0.51	1.43	1.11	0.66	1.55	1.21	2.11	11.07	8.27
2008	0.51	1.43	1.09	0.65	1.54	1.21	2.10	11.06	8.21
2009	0.50	1.42	1.08	0.65	1.54	1.20	2.10	11.06	8.16
2010	0.50	1.42	1.07	0.65	1.54	1.19	2.10	11.05	8.11
2011	0.50	1.42	1.07	0.65	1.54	1.19	2.10	11.05	8.10
2012	0.51	1.43	1.08	0.65	1.54	1.19	2.10	11.05	8.09
2013	0.51	1.43	1.08	0.66	1.54	1.19	2.10	11.04	8.07
2014	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.06
2015	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.05
2016	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.05
2017	0.52	1.44	1.09	0.67	1.55	1.20	2.10	11.04	8.05
2018	0.52	1.44	1.09	0.67	1.55	1.20	2.10	11.04	8.05
2019	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2020	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2025	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2030	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05

Adjustment notation:

(1) LDGV's: Adjust VOC downward by 0.14 gpm for 1995 through 2030 to reflect decrease in exhause emission standard from 0.39 gpm to 0.25 gpm.

(2) LDGV'S: Assume NO_x emissions of 0.50 gpm beginning in 1995 and forward to reflect new/in-use standard fo 0.40 gpm and 0.6 gpm 100,000-mile certification standard.

(3) LDGV's: CO emission factors include new cold temperature standards.

(4) LDDV's: MOBILE4.1 emission factors are below standards; therefore no adjustments to LDDV emission factors are necessary.

(5) HDDV's: MOBILE4.1 incorporates 1994 HC and CO standards. NO_x standard was lowered, but MOBILE4.1 produces forcast emission factors at about the same level as the standards.

Table E-74. EPA Highway Vehicle Classification Categories and Definitions

Vehicle-Type Classification Category	EPA Category Definition
Light-duty gasoline-powered vehicles (LDGVs)	Gas-fueled vehicle primarily designed for passenger transportation with a design capacity of 12 persons or less.
Light-duty gasoline-powered trucks, Class 1 (LDGT1s)	Diesel-fueled vehicle primarily designed for passenger transportation with a design capacity of 12 persons or less.
Light-duty gasoline-powered trucks, Class 2 (LDGT2s)	Gas-fueled vehicle with a Gross Vehicle Weight (GVW) between 6,001 and 8,500 pounds.
Heavy-duty gasoline-powered vehicles (HDGVs)	Gas-fueled vehicle designed to carry property, with a Gross Vehicle Weight (GVW) over 8,500 pounds, or; any vehicle designated for passenger transportation having a design capacity of more than 12 persons.
Light-duty diesel-powered vehicles (LDDVs)	Any diesel-fueled vehicle designated primarily for passenger transportation and having a design capacity of 12 persons or less.
Light-duty diesel-powered trucks (LDDTs)	Any diesel-fueled vehicle designed primarily for property transportation, and rated at 8,500 lbs. GVW or less.
Heavy-duty diesel-powered vehicles (HDDVs)	Any diesel-fueled vehicle designed primarily for property transportation, and rated at more than 8,500 lbs. GVW.

Source: U.S. Environmental Protection Agency, *Supplement A to AP-42 Volume II*, January 1991.

DAC obtained the MOBILE4.1 model from the EPA, and used the model to calculate national CO, NO_x, and VOC emission factors to the year 2020 (the last MOBILE4.1 forecast year) using a scenario-based input data set. EPA staff make the assumption that emission factors remain relatively stable after 2010.[82] Therefore, emission factors for 2020 are used for the subsequent forecast years. As already noted, the MOBILE4.1 emission factors do not reflect many new CAAA standards that should affect emission rates after 1993. Post hoc adjustments need to be made to account for new vehicle standards, in-use standards, and other CAAA emission control requirements if the forecasted emission factors exceed the standards in any year. It is important to note that any emission factor adjustments are based on gross assumptions, with the resulting emission factors considered to be interim in nature.

The MOBILE4.1 input data set consists of a series of user-specified control flags, data inputs common to all emission scenarios, and data inputs specific to an individual scenario. In addition to regulating program execution and input/output stream formatting, the control flags determine model actions such as the use of emission control device tampering rates, average vehicle speed selection, mileage accumulation rate selection, VMT mix selection, I/M program impact, ambient temperature selection, and many other factors. Control flags specifying EPA default values and national averages were included to the maximum extent.

[82] Personal communication with Lois Platte, EPA Motor Vehicle Emission Laboratory, Ann Arbor, Michigan, June 26, 1992.

The greatest difficulty in developing the MOBILE4.1 data set was accounting for the impact of inspection/maintenance programs. MOBILE4.1 was not designed with the capability for estimating national average I/M program impacts. The I/M program data set record must be specified according to local I/M program attributes. Such program attributes are highly customized to met locale-specific implementation needs, and therefore cannot be formulated into a national average I/M program. Further complications result from the fact that I/M programs are not required nor implemented in many areas of the country, and new EPA regulations have resulted in greater complexity for existing and planned programs.

To account for the effects of I/M and anti-tampering programs on emission factors, a model-run interpolation method was used. Inspection and maintenance programs are required for 162 ozone areas based on CAAA regulations. A data set was created that included parameters and data for an "enhanced" I/M model program (required for serious, severe, and extreme ozone nonattainment areas) as outlined in the EPA's Notice of Proposed Rulemaking.[83] An enhanced I/M program includes annual centralized testing for light-duty vehicles and trucks, and include such tests as the transient IM240 exhaust emission test, the transient purge test, the pressure test, the two-speed exhaust test, and the idle exhaust test. The EPA estimates that such an I/M program could reduce vehicle VOC emissions by 28 percent, CO emissions by 30 percent, and NO_x emissions by 9 percent.[84]

A MOBILE4.1 emission factor based on national imposition of enhanced I/M programs is assumed to represent an upper bound for vehicle emissions. To account for areas that have no I/M and anti-tampering programs, a MOBILE4.1 data set was created that excluded operating I/M and anti-tampering programs. Separate sets of emission factors were generated from MOBILE4.1 model runs employing each data set. Composite emission factors were derived by taking the arithmetic average of the two emission factor sets. Ideally, the composite emission factor set should be calculated as a weighted average, using vehicle mileage data for each type of ozone nonattainment area and I/M program type. Such a procedure is complex and time-consuming (and perhaps not doable because of the flexibility afforded to the states for choosing I/M program elements), and could not be attempted given the resources available for this subtask. The simple arithmetic average approach, while producing somewhat arbitrary results, is superior to assuming a universally-applied I/M program for all areas of the country. Such an assumption yields overly-optimistic emission factor reductions.

[83] EPA Notice of Proposed Rulemaking, "Vehicle Inspection and Maintenance Requirements for State Implementation Plans," 40 CFR Part 51, July 9, 1992.

[84] Ibid., section II.

Sulfur Dioxide and Carbon Dioxide Emission Factors: Conventional Vehicles

The EPA does not regularly monitor and report carbon dioxide and sulfur dioxide emissions for highway mobile sources. The relatively small amounts of SO_2 emitted by trucks and cars are quickly converted to sulfuric acid, and therefore do not represent a significant air pollution hazard. Although the EPA produced SO_2 measurement procedures in the early 1980's, the Agency has not published SO_2 emission factors.[85]

The SO_2 and CO_2 emission factors to be used in TERF come from the Argonne National Laboratory's Transportation Energy and Emissions model (TEEMS). Table E-82 provides the emission factors produced for the DOE Office of Environmental Analysis as part of data input to the NESEAM model.[86] These emission factors include the effects of CAAA emission standards, and are forecasted to the year 2030.

The TEEMS/NEASAM emission factors were reported in pounds of emissions per million Btu. To convert the emission factors to a grams-per-mile equivalent, the following formula was used:

$$EF_{gpm} = EF_{ppBtu} \text{ x } 57.9549 / MPG_c$$

where:

EF_{gpm} = Emission factor in grams per mile,
EF_{ppBtu} = TEEMS emission factor in pounds per million Btu,
MPG = TEEMS forecasted fuel economy for category c vehicles in gallons per mile,

The TEEMS model does not report CO_2 emission factors for heavy-duty diesel trucks and heavy-duty gasoline vehicles.

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85 Personal communication with Penny Carey, EPA Motor Vehicle Emissions Laboratory, Ann Arbor, Michigan, August 4, 1992.

86 See, *Decision Analysis Corporation, Mobile Source Air Emissions Regulations and Inventories, Draft Report*, (Prepared for the EIA Energy Demand Analysis Branch under Contract No. DE-AC01-92EI21946, July 15, 1992).

Table E-75. LDV Sulfur Dioxide and Carbon Dioxide Emission Factors (Grams/Mile)

YEAR	SO2					CO2		
	HDDT	HDGV	LDDT	LDGT	LDGV	LDDT	LDGT	LDGV
1990	1.3892	0.3890	0.5156	0.0968	0.0846	178.2613	178.2613	98.0075
1991	1.0592	0.3913	0.3898	0.0957	0.0827	176.1273	176.1273	96.8204
1992	0.8075	0.3937	0.2947	0.0947	0.0809	174.0188	174.0188	95.6477
1993	0.6157	0.3961	0.2228	0.0937	0.0791	171.9355	171.9355	94.4891
1994	0.4694	0.3985	0.1685	0.0927	0.0773	169.8771	169.8771	93.3446
1995	0.3579	0.4009	0.1274	0.0917	0.0756	167.8435	167.8435	92.2140
1996	0.3586	0.3987	0.1263	0.0913	0.0747	167.1971	167.1971	91.5909
1997	0.3593	0.3966	0.1253	0.0910	0.0738	166.5531	166.5531	90.9719
1998	0.3600	0.3945	0.1243	0.0906	0.0729	165.9117	165.9117	90.3572
1999	0.3607	0.3924	0.1233	0.0902	0.0721	165.2728	165.2728	89.7466
2000	0.3615	0.3904	0.1222	0.0898	0.0712	164.6363	164.6363	89.1402
2001	0.3540	0.3895	0.1206	0.0887	0.0705	162.6740	162.6740	87.8486
2002	0.3467	0.3886	0.1190	0.0875	0.0698	160.7351	160.7351	86.5757
2003	0.3396	0.3877	0.1174	0.0863	0.0691	158.8193	158.8193	85.3213
2004	0.3326	0.3869	0.1158	0.0852	0.0684	156.9264	156.9264	84.0850
2005	0.3258	0.3860	0.1143	0.0841	0.0678	155.0560	155.0560	82.8667
2006	0.3191	0.3851	0.1127	0.0830	0.0671	153.2080	153.2080	81.6660
2007	0.3125	0.3843	0.1112	0.0819	0.0664	151.3819	151.3819	80.4827
2008	0.3061	0.3834	0.1097	0.0808	0.0658	149.5776	149.5776	79.3166
2009	0.2998	0.3825	0.1082	0.0797	0.0651	147.7948	147.7948	78.1673
2010	0.2936	0.3817	0.1068	0.0787	0.0645	146.0333	146.0333	77.0347
2020	0.31806	0.413476	0.10608	0.076857	0.063419	146.0333	146.0333	77.03472
2030	0.31806	0.413476	0.10608	0.076857	0.063419	146.0333	146.0333	77.03472

Source: Argonne National Laboratory Transportation Energy and Emissions Modeling System (TEEMS), Model run ANL-90N.

Total Carbon Emission Factors: Conventional Vehicles

The calculation of total carbon emission factors for gasoline and diesel fuels is straightforward. The following formulae are used to produce carbon emission factors in grams per mile:

$$CarbonEF_{gas} = 0.866 * (2791.0/MPG)$$
$$CarbonEF_{diesel} = 0.858 * (3192.0/MPG)$$

The constant values of 0.886 and 0.858 are the carbon mass fractions of gasoline and diesel, respectively.[87] The constant values of 2791 and 3192 are the densities for gasoline and diesel fuel, and were obtained from EIA's *1989 International Energy Annual* (February 1991).[88] To obtain the carbon emission factors, the endogenously calculated TERF miles-per-gallon estimates (MPG) will need to be passed to the emissions module. As currently configured, MPG forecasts will be determined using the Argonne National Laboratory TEEMS methodology, which uses lagged MPG and other economic variables.

Using Argonne's ANL-90N TEEMS run as an example, automobile and diesel freight truck carbon emission factors for 1990, 1995, 2005 and 2010 are shown below (MPG figures are in parentheses).

Year	Emission Factor, g/mile (MPG)	
	Automobiles	Light Trucks
1990	120.8 (20.0)	464.2 (5.9)
1995	119.5 (20.7)	449.0 (6.1)
2000	116.1 (21.3)	427.9 (6.4)
2005	107.5 (23.0)	421.3 (6.5)
2010	89.3 (27.7)	415.0 (6.6)

[87] This value is reported by the EPA. See, Frank Black, 3rd U.S. - Dutch International Symposium, "Atmospheric Ozone Research and Its Policy Implications" (May 9-13, 1988, Nijmegen, the Netherlands), or the DeLuchi/Argonne greenhouse gas study.

[88] Appendix F, Volume, Weight, and Monetary Conversions, p. 149.

Emission Factors: Alternative Fuel Vehicles

The calculation of emission factors for alternative fuel vehicles (AFVs) is subjective in nature, and depends on emissions data from test vehicles and the likely capability of AFVs to meet new CAAA clean-fuel vehicle emission standards. Emission factors for NMHC, CO, NO_x, and CO_2 were provided to Argonne National Laboratory in a greenhouse gas emission study conducted jointly by the Institute of Transportation Studies at the University of California-Davis, and the Center for Energy and Environmental Studies at Princeton University.[89] Table E-83 lists these AFV emission factors for light-duty vehicles (LDV's) and heavy-duty vehicles, such as freight trucks and buses (HDV's), powered by the following fuels: methanol (100%), compressed natural gas, hydrogen, ethanol (100%), and liquid petroleum gas (LPG). Electric vehicles are considered to emit no pollutants other than a small quantity of chlorofluorocarbons (CFCs).

Table E-76. Lifetime Average Emission Factors for Alternative Fuel Vehicles (Grams per Mile)

	Methanol*		**Natural Gas**		**Hydrogen**		**Ethanol***		**LPG**	
	LDV	**HDV**	**LDV**	**HDV**	**LDV**	**HDV**	**LDV**	**HDV**	**LDV**	**HDV**
NMHC	0.56	4.86	0.22	0.60	0.04	0.04	0.38	4.42	0.22	1.80
CO	7.21	13.00	3.60	7.00	0.70	0.10	7.21	13.00	5.50	9.00
NO_x	0.45	8.05	0.45	8.05	0.45	8.05	0.45	8.05	0.45	8.05
CO_2	214.64	1495.41	195.51	1463.94	0.00	0.00	0.00	0.00	226.72	1695.56

*Emission factors are for M100 (100% methanol) and 100% ethanol fuels.

[89] Mark A. DeLuchi, University of California Institute of Transportation Studies, *Emissions of Greenhouse Gases From the Use of Transportation Fuels and Electricity* (for the Argonne National Laboratory Center for Transportation Research, June 26, 1991).

OFF-HIGHWAY SOURCES EMISSIONS FACTORS

Off-Highway Mobile Source Emission Factor Information Sources

The following documents were used to compile off-highway emission factors or supply background information on emission factor calculation methods:

- *Compilation of Air Pollutant Emission Factors - Volume II: Mobile Sources* (AP-42, Fourth Edition, September 1985)

- *Nonroad Engine and Vehicle Emission Study—Report*, EPA 460/3-91-02 (November 1991)

- *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachments A through J (This EPA memorandum supersedes the mobile source emission inventory preparation instructions contained in *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, which is currently being revised)

- *Procedures for Emission Inventory Preparation —Volume IV, Mobile Sources*, EPA-450/4-81-026d (revised), (July 1992).

The document, *Compilation of Air Pollutant Emission Factors - Volume II*, reports all data and emission factor calculation algorithms for both highway and off-highway emission sources. Section II outlines the emission calculation methodologies for off-highway mobile sources, including aircraft, railroad locomotives, inboard-powered vessels, outboard-powered vessels, small general utility engines, agricultural equipment, heavy duty construction equipment, and snowmobiles. The EPA is planning to issue an updated version of the AP-42 document, although no estimate has been given as to the release date. The EPA's *Nonroad Engine and Vehicle Emission Study*, which was mandated as part of CAAA Section 213(a), provides new or updated emission inventory data and emission factors for ten nonroad equipment categories including commercial marine vessels, which is one of the transport modes to be modeled in TERF.[90] The Nonroad Emission study targeted 24 nonattainment areas as well as national totals. The document, *Procedures for Emission Inventory*

[90] The other nine equipment categories are lawn and garden equipment, airport service equipment, recreational vehicles, recreational marine equipment, light commercial equipment, industrial equipment, construction equipment, agricultural equipment, and logging equipment.

Preparation — Volume IV, Mobile Sources, provides state and local agencies with detailed guidance on the preparation of highway and off-highway mobile source emission inventories. The off-highway emission factors contained in this section were derived either directly from the inventory preparation procedure report, or were calculated using data tables contained therein.

Railroad Locomotive Emission Factors

Table E-84 lists the railroad locomotive emission factors to be incorporated into the TERF model. Emission factors for CO, NO_x, SO_2 and HC are included.[91] Note that the EPA does not measure separately the volatile component of total hydrocarbons. Also, no distinction is made between freight and passenger locomotives because both travel modes use the same locomotive technology types. These emission factors are reported in the July 1992 edition of *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*. They are considered default values for fleet-average line haul locomotives.[92] Line haul locomotives represent the largest segment of the locomotive population, and include all locomotives used for freight and passenger service. As of mid-1991, 9,708 line haul locomotives were in service.[93] Yard locomotives are used for moving railcars within a rail switchyard, and are considered a negligible source of emissions. As of mid-1991, 4,589 yard locomotives were in service.[94]

The emission factors represent an average of emission factors for five diesel engine configuration types: 2-stroke supercharged switch locomotive, 4-stroke switch locomotive, 2-stoke super-charged road service locomotive, 2-stroke turbocharged road service locomotive, and 4-stroke road service locomotive. The emission factors are based on duty cycle testing and average fuel consumption rates. A duty cycle consists of the operating time in eight throttle notch settings plus idle and dynamic braking. The fuel consumption rate of a locomotive is determined by the throttle notch position — the higher the notch, the higher the fuel consumption, and vice versa. Therefore, fuel consumption is proportional to the amount of time the locomotive spends in each throttle notch position.[95] The locomotive emission factors apply to all three Interstate Commerce Commission

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[91] Source: EPA Office of Mobile Sources, *Locomotive Emission Factors for Inventory Guidance Document* (June 1991).

[92] The EPA also outlines a methodology for calculating more detailed locomotive emissions for areas that are expected to deviate significantly from the national average. The methodology is called the *roster tailoring method*, and uses emissions data from individual locomotive makes and models.

[93] *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachment J, Emissions from Railroads (EPA Office of Mobile Sources, February 15, 1992), Appendix 6-5, p. 6-23.

[94] Ibid, p. 6-23.

[95] Ibid, p. 6-13.

(ICC) railroad classes: Class I — annual revenues greater than $93.5 million; Class II — annual revenues greater than $18.7 million but less than $93.5 million; Class III — annual revenues less than $18.7 million.

Table E-77. TRAN Locomotive Emission Factors

Pollutant	Emission Factor (lbs./1,000 gal of fuel)
HC	21.10
CO	6.26
NO_x	493.10
SO_2*	36.00
PM	11.60

*Based on fuel sulfur content of 0.25 percent by weight.

Look-Ahead Issues Concerning Locomotive Emission Factors

In terms of specifying future-year locomotive emission factors given CAAA requirements, the emission factors in Table E-84 are to be used for all forecast years. Section 213 of the Amended Act requires the EPA to promulgate emission standards for new locomotives by November 1995. These new standards are to be designed to obtain the greatest degree of emission reduction achievable, with due consideration given to compliance cost, energy consumption, safety and noise.[96] New emission factors would be based on testing of the applicable locomotive emission reduction technologies that would be manufactured to comply with new standards. Given the large uncertainty over the prospective emission standards and technologies, as well as the low stock turnover of locomotive engines, there is no justification for assigning alternative emission factors to the forecast interval.

Aircraft Emission Factors

Overview of the EPA Aircraft Emissions Inventory Methodology

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[96] CAAA, sec. 213 (a)(5), 104 STAT 2501.

The EPA bases its aircraft emission factors on five operating modes that together consist of the landing and takeoff (LTO) cycle. The first operating mode is the approach, in which the aircraft makes its airport approach after the descent from cruising altitude. The second operating mode is taxi/idle-in, where the aircraft lands and taxis to the gate. The third mode is taxi/idle-out, in which the aircraft taxis back out to the runway for subsequent takeoff.[97] The fourth mode is takeoff, in which the aircraft attains liftoff speed and becomes airborne. The fifth mode is termed the climbout, and represents the aircraft's accent to cruising altitude. Most aircraft go through a similar sequence during an LTO cycle.

During each operation mode the aircraft engines operate at a fairly standard power setting for a given aircraft category. The power setting results in a certain rate of fuel flow (expressed in pounds per minute) for the operating mode. Total emissions from the aircraft engine are thus determined by the amount of time that an aircraft engine spends in each operation mode (termed the "Time-in Mode"), the fuel consumption rate, and the engine-specific emission factors for each operating mode, expressed in pounds of emissions per 1,000 pounds of fuel consumed.

The EPA aircraft emission factors and inventory preparation procedures are site-specific; they are highly dependent on local airport and aircraft population data. Generally, the emissions inventory is prepared using the following steps: (1) identify airports to be included in the inventory area, (2) determine the mixing height[98] to be applied to the LTO cycle (a standard default value of 3,000 feet is assumed), (3) define the aircraft fleet population for each aircraft category across all airports, (4) determine the number of LTOs for each aircraft category, (5) select emission factors for each aircraft category, (6) estimate a time-in-mode for each aircraft category at each airport, and (7) calculate an inventory based on the airport activity, time-in-mode, and emission factors.

EPA Aircraft Categorization

The EPA categorizes aircraft by the type of use: commercial, general aviation, and military. Commercial aircraft include those used for scheduled service transporting passengers, freight, or both. Air taxis also fly scheduled service carrying passengers and/or freight, but usually are smaller aircraft and operate on a more limited basis than the commercial carriers. Business aircraft support

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[97] Both Taxi/idle operating modes are highly variable, and depend on such factors as airport size and layout, the amount of ground congestion, airport-specific operational procedures, time of day, and seasonal travel activity.

[98] The height of the mixing zone — that portion of the atmosphere where aircraft emissions affect ground level pollutant concentrations — influences the time-in-mode for approach and climbout operation modes, and is particularly significant when calculating NO_x emissions.

business travel, usually on an unscheduled basis, and general aviation includes most other non-military aircraft used for recreational flying, personal transportation, and various other activities.

The EPA combines business aircraft with general aviation aircraft because of their similar size, use frequency, and operating profiles. Similarly, air taxis are treated much like the general aviation category because they are typically the same types of aircraft. Military aircraft cover a wide range of sizes, uses, and operating missions. While they often are similar to civil aircraft, they are handled separately because they typically operate exclusively out of military air bases and frequently have distinctive flight profiles. Helicopters, or rotary wing aircraft, can be found in each of the categories. Their operation is distinct because they do not always operate from an airport but may land and takeoff from a heliport at a hospital, police station, or similarly dispersed location. Military rotorcraft are included in the military category and non-military rotorcraft are included in the general aviation category since information on size and number are usually found in common sources. However, they are combined into a single group for calculating emissions since their flight profiles are similar.

Commercial aircraft typically are the largest source of aircraft emissions. Although they make up less than half of all aircraft in operation around a metropolitan area, their emissions usually represent a large fraction of the total because of their size and operating frequency. This would not hold true for a city with a disproportionate amount of military activity, or a city with no major civil airports.

Aircraft Emissions Characteristics

The EPA views HC, CO, NO_x, SO_2, and PM_{10} as the significant aircraft pollutants. However, only HC emissions and smoke production are currently regulated.[99] For a single LTO cycle, aircraft emissions vary considerably depending on the category of aircraft and the aircraft's flight profile. Emission rates for HC and CO are high during the taxi/idle phases when aircraft engines are at low power and operate at suboptimum efficiency. The emission rates fall as the aircraft moves into the higher power operating modes of the LTO cycle. Conversely, NO_x emissions are low when engine power and combustion temperature are low, but increase as the power level is increased and combustion temperature rises. Therefore the takeoff and climbout modes have the highest NO_x emission rates.

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[99] EPA established standards for aircraft HC emissions in 1984, which included the establishment of standard procedures for engine certification and emissions testing. The standard applies to jet engines with an engine thrust of over 6,000 pounds. The EPA reports that many older in-service engines exceed the standards. New engine designs produced since the standards went into effect have HC emissions lower than the standards, but the design changes made to reduce the HC emissions resulted in small increases in NO_x emissions.

Sulfur dioxide emission rates are highest during the takeoff and climbout operation modes when fuel consumption rates are high. Sulfur emissions typically are not measured when aircraft engines are tested. Therefore, the EPA uses a default emission factor of 0.54 pounds SO_2 per 1,000 pounds of fuel for all engine types. (EPA assumes that all sulfur in the fuel combines with oxygen during combustion to form SO_2. Nationally, the sulfur content of fuel remains fairly constant from year to year at about 0.05% by weight for commercial jet fuel, 0.025% by weight for military fuel, and 0.006% by weight for aviation gasoline. These national sulfur content figures are used by the EPA for estimating the SO_2 default emission factors.

Particulate emission characteristics are similar to that of HC and CO in that emission rates are higher at low power rates than at high power rates because of greater combustion efficiency at a higher engine power. However, particulate emissions are highest during takeoff and climbout due to the greater fuel flow rate. The EPA does not report emission factors for particulates except for a small number of engine models, citing the difficulty in estimating PM emissions.[100] Direct measurement of particulate emissions from aircraft engines typically are not available from manufacturers, although emission of visible smoke is reported as part of the engine certification procedure.[101] The inventory preparation procedure document reports emission factors for only one civil aircraft engine model. This engine model is used in a number of European-built aircraft, and is not representative of the total aircraft fleet.

Methodology for Calculating Aircraft Emission Factors

As mentioned above, the EPA aircraft emission factors are reported for individual engine models (currently 88 civil aircraft engines and 54 military engines) by LTO operation mode. Consequently, the emission factors apply to activity levels measured in full LTO cycles, not fuel consumption as specified in the TSCDR. A methodology was developed for converting the EPA operating-mode emission factors into a fleet average emission factor based on total gallons of fuel consumed. The data used to construct the fuel-based emission factors are presented in Appendix E.EM.C.

The first step of the conversion methodology involves the derivation of fleet-average time-in-mode figures. The EPA reports default TIM values in minutes for each civil and military aircraft category. Since commercial aircraft accounted for 93.6 percent of civil aircraft energy consumption in 1989, the TIM values for jumbo, long, and medium range jet commercial carriers were used as

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[100] *Procedures for Emission Inventory Preparation, Vol IV*, page 149.

[101] Ibid., p. 149.

proxies for the entire civil aircraft population.[102] These TIM figures are as follows: Takeoff — 0.7 minutes, Climbout — 2.2 minutes, Approach — 4.0 minutes, Taxi/Idle — 26.0 minutes. Military aircraft TIM's are highly variable. Therefore, the arithmetic averages of TIMs for combat, trainer, and transport aircraft were used as proxies for the fleet TIMs. Helicopter TIMs were excluded from the calculations due to LTO incompatibility with the other aircraft categories.

The second step of the conversion methodology is to determine the fuel use for each operating mode using the EPA's fuel flow data, and to construct fuel consumption shares. The LTO time-in-mode amounts (in minutes) were multiplied by the fuel flow amounts (in pounds per minute) to obtain fuel consumption in pounds for each operating mode. The modal fuel consumption figures were then divided by total LTO fuel consumption to derive the fuel consumption shares (see Appendix E.EM.C, pages E.EM.C-3 and E.EM.C-6).

The third step is to calculate average emission factors by pollutant type for the population of engine models reported by the EPA. Separate samples of 46 civil and 15 military aircraft engine models were created from the EPA's list.[103] The selection was based on reported engine market shares for each aircraft model, with aircraft models chosen based on a proportional representation of the commercial, general and military aircraft categories. The sample engine-model emission factors were aggregated by calculating the arithmetic average of reported pollutant emission factors.[104] (see Appendix E.EM.C, pages E.EM.C-1, E.EM.C-2, E.EM.C-4, and E.EM.C-5). Since the SO_2 emission factor is the same for each operation mode, this methodology is not applicable for SO_2 emission rate estimation.

The fourth step is to calculate the weighted fleet-average emission factors for HC, CO, and NO_x by multiplying the aggregated engine sample emission factors by the fuel consumption shares calculated in step 2. Two further calculations are necessary to produce emission factors that correspond to TSCDR specifications. First, the emission factors must be converted into gallons-of-fuel equivalents. A conversion factor of 6.2 pounds per gallon was used. Second, the total HC emission factors must be adjusted to produce volatile organic compound (VOC) emission factors. The following EPA adjustment factors, applicable to turbine engines, were used:

$$VOC_{COMMERCIAL} = THC_{COMMERCIAL} \times 1.0947$$

[102] Aircraft Btu energy consumption figures come from Oak Ridge National Laboratory, *Transportation Energy Data Book, Edition 12*, ORNL-6710 (Oak Ridge, Tennessee, March 1992).

[103] *Procedures for Emission Inventory Preparation*, Table 5-4, "Commercial Aircraft types and Engine Models," and Table 5-6, "Military Aircraft types and Engine Models."

[104] Ibid., Table 5-4, "Modal Emission Rates."

$$VOC_{MILITARY} = THC_{MILITARY} \times 1.1046$$

Table E-85 presents the aircraft emissions factors for HC, VOC, CO, NO_x, and SO_2.[105]

Table E-78. Aircraft Emission Factors

Pollutant	Emission Factors (lbs./1000 gal. of fuel)	
	Commercial Aircraft	Military Aircraft
HC	37.82	75.54
VOC	41.40	83.44
CO	101.97	330.17
NO_x	79.04	58.15
SO_2	3.35	3.35

Look-Ahead Issues Concerning Aircraft Emission Factors

Among the factors expected to influence aircraft emission rates in a forecasting context are the following:

- new aircraft engine designs,
- airport noise regulations,
- an increase in airport congestion problems

Aircraft with cleaner and more energy-efficient engine designs are expected to continue to slowly penetrate the world aircraft fleet population. Since there is a significant engineering and development leadtime for producing new aircraft engines, most of the commercial aircraft to be added to the fleet in the next five to seven years will be powered by engines currently monitored by the EPA.[106] Given the 12-year average service life for commercial aircraft engines, the newer generation of aircraft engines are not expected to make a significant impact on national emission

[105] Source: Appendix E.EM.C, page E.EM.C-3;

Notes: Commercial and military VOC emission factors calculated by multiplying Appendix E.EM.C HC values by 1.0947 and 1.1046, respectively.

SO_2 emission factors calculated by dividing the EPA standard value of 0.54 pounds per 1,000 gallons by 6.2.

[106] Ibid., p. 208.

levels until 2010. However, a possible catalyst for an increased rate of new aircraft engine market penetration is the recent enactment of national airport noise regulations, which require the phase-out of loud aircraft by 2000. Airlines are expected to upgrade their fleets with quieter and cleaner engines once the industry formulates compliance plans. The extent of the emission rate impact of such fleet upgrading is unknown at this time.

Acting as a counterweight on the downward pressure on emission rates caused by stock turnover and new regulations is the growth in air travel combined with limited excess capacity at many airports. Air travel has experienced strong growth over the past several years, and this growth is expected to continue for the foreseeable future. The primary capacity squeeze will be felt at small feeder airports and regional hubs. Increased congestion at capacity-constrained airports will increase taxi/idle times, resulting in increased emissions per LTO.

Given these offsetting impacts on aircraft emissions, the emission factors listed in Table E-85 should be satisfactory for estimating future aircraft emission levels.

Waterborne Vessel Emission Factors

Commercial Vessels

Table E-87 provides the EPA emission factors for domestic commercial motorships. These emission factors are reported in the AP-42 document. The emission factors are based on Army Corps of Engineers waterway classification categories, which are defined as follows:

- **River —** All waterborne traffic between ports or landings wherein the entire movement takes place on inland waterways.
- **Great Lakes —** All waterborne traffic between United States ports on the Great Lakes.
- **Coastal —** All domestic traffic receiving a carriage over the ocean or between the Great Lakes ports and seacoast ports when having a carriage over the ocean.

To derived an average emission factor for all three waterway category vessels, a weighted-average methodology was applied whereby shipment tonnage and average length-of-haul data from the Army Corps of Engineers were used to construct emission factor weights.[107] Table E-87 provides

[107] U.S. Army Corps of Engineers, *Waterborne Commerce of the United States, Calendar Year 1989* (Waterborne Statistics Center, New Orleans, LA, 1991), Part 5: National Summaries, pp. 32, 93.

more details on the weighting methodology.

The EPA *Nonroad Engine and Vehicle Emission Study Report* provides emission factors for two additional vessel categories: ocean-going steamships and harbor/fishing vessels.[108] These emission factors are based on engine sizes and operating mode (hoteling, cruise, and full power), and are not compatible with the emission factors provided in Table E-89. Because of the small emissions contribution of these vessels to the overall waterborne vessel total, they are not included in the composite waterborne vessel emission factors. For reference purposes, Appendix E.EM.D provides the ocean-going and harbor/fishing vessel emission factor tables from the Nonroad Engine and Vehicle report.

Table E-79. Commercial Vessel Emission Factors[109] (Pounds per 1,000 gallons of fuel)

Pollutant	**Waterway Class**			**Weighted Average***
	River	**Great Lakes**	**Coastal**	
HC	50	59	50	51
CO	100	110	110	107
NO_x	280	260	270	273
SO_2	27	27	27	27

* Average emission factors calculated by multiplying pollutant emission factors for each waterway class by shipment mileage weights and then summing the weighted emission factor values. The shipment weights are as follows: River — 0.34, Great Lakes — 0.07, Coastal — 0.59. Shipment mileage weights were derived by multiplying tons shipped by the average length-of-haul per ton shipped for each waterway class.

Recreational Vessels

Table E-87 provides HC, CO, and NO_x emission factors for recreational marine vessels. These emission factors come from the EPA *Nonroad Engine and Vehicle Emission Study Report*. The EPA classifies and reports emission factors for the following vehicle/engine types:

- vessels with inboard engines (4-stroke)

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[108] These emission factors were compiled and provided to the EPA in a Booz Allen & Hamilton report, *Commercial Marine Vessel Contributions to Emission Inventories* (Los Angeles, CA, October 7, 1991).

[109] U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors, Volume II: Mobile Sources*, AP-42, PB-87-205266 (EPA Office of Mobile Sources, September 1985), Part II, Off-Highway Mobile Sources, Table II-3.1.

U.S. Army Corps of Engineers, *Waterborne Commerce of the United States, Calendar Year 1989* (Waterborne Statistics Center, New Orleans, LA, 1991), Part 5: National Summaries, pp. 32, 93.

- vessels with outboard engines (2-stroke)
- vessels with sterndrive engines (4-stroke)
- sailboats with auxiliary outboard engines (diesel)
- sailboats with auxiliary inboard engines (diesel)

When the AP-42 document was compiled, emission testing data was not available for recreational marine vessels. The EPA used coast guard diesel engine and automotive engine emission data to compute in-board emission factors based on the duty-cycle for engines classified as large out-boards. Out-board emission factors were derived from data supplied to the EPA by the Southwest Research Institute.

For the Nonroad Engine and Vehicle report, outboard engine emission factors were derived from test data supplied to EPA by the National Marine Manufacturers Association, which tested 25 two-stroke and three four-stroke outboard engines. For four-stroke outboards, emission factors recommended by the Southwest Research Institute were used for particulate matter emissions.[110] Since no data were available for 2-stroke outboard engine particulate matter emissions, EPA used emission factors from the CARB Technical Support Document for utility and lawn/garden equipment as approximations. For inboard/sterndrive gasoline engines, the EPA derived emission factors on the basis of test data on three 4-stroke gasoline marine inboard/sterndrive engines supplied by NMMA. The particulate emission factor used was 1.64 pounds per 1,000 gallons of fuel. The EPA used NMMA test data for a small diesel sailboat inboard and three large diesel inboard engines as the basis for calculating emission factors for inboard diesel engines.

As with the commercial marine vessels, vessel/engine-type emission factors must be weighted according to an activity or population level indicator and summed to obtain an average emission factor for the total recreational marine vessel population. Engine population data for each vessel/engine-type class was used to construct the weights. Boat population figures were gathered from local boat registration data bases, and were subsequently adjusted to obtain engine population estimates. Energy and Environmental Analysis developed the engine number derivation methodology for the EPA.

[110] U.S. Environmental Protection Agency, *Designation of Areas for Air Quality Planning Purposes*, 40 CFR Part 81, Final Rule, Washington, D.C., Office of Air and Radiation, November 6, 1991.

Table E-80. Recreational Marine Vessel Emission Factors[111] (Pounds per 1,000 gallons of fuel)

Pollutant	Vessel/Engine Type				Weighted Average*
	Outboard/ 2-Stroke	Outboard/ 4-Stroke	Sterndrive/ 4-Stroke	Sailboard/ Diesel Aux.	
HC	1610	190	160	50	1233
CO	2990	3130	2680	80	2884
NO_x	20	150	100	380	44

* Weights for each vessel/engine-type category were constructed from the following engine population figures: Outboard/2-Stroke — 8,204,304, Outboard/4-Stroke — 41,228, Sterndrive/4-Stroke — 2,713,420, Sailboat/Diesel-Aux. — 114,502.

Table E-81. Ocean-Going Commercial Vessel Emission Factors

OPERATING PLANT Operating Mode/Rated Output	POLLUTANT				
	NO_x	HC	CO	SO_x	PM
STEAM PROPULSION					
Full Power	63.6	1.72	7.27	159x(%S)	56.5
Maneuver/Cruise	55.8	0.682	3.45	159x(%S)	20
Hotelling					
- Burning residual bunker fuel	36.4	3.2	*	159x(%S)	10
- Burning distillate oil	22.2	3	4	142x(%S)	15
MOTOR PROPULSION					
All underway operating modes	550	24	61	157x(%S)	33
AUXILLARY DIESEL GENERATORS					
- 20 KW (50% Load)	477	144	53.4	27	17
- 40 KW (50% Load)	226	285	67.6	27	17
- 200 KW (50% Load)	140	17.8	62.3	27	17
- 500 KW (50% Load)	293	81.9	48.1	27	17

Notes:
1) Emissions factors showing an asterisk (*) are considered negligible for these operating modes.
2) Average sulfur concentrations used are 0.8 percent for marine diesel, and 2.0 percent for bunker fuel oil.

Sources:
1) U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, 1985.
2) U.S. Department of Transportation, Port Vessel Emissions Model, 1986.
3) California Air Resources Board, Report to the California Legislature on Air pollutant Emissions from Marine Vessels.

[111] U.S. Environmental Protection Agency, *Nonroad Engine and Vehicle Emission Study — Report*, EPA 460/3-91-02 (EPA Office of Mobile Sources, November 1991), Table 2-03, Appendix I, Table I-11.

Table E-82. Harbor and Fishing Vessel Emission Factors

OPERATING PLANT Operating Mode/Rated Output	POLLUTANT NO_x	HC	CO	SO_x	PM
DIESEL ENGINES	Pounds per Thousand Gallons of Fuel Consumed				
< 500 Horsepower					
Full	275.1	21	58.5	157x(%S)	17
Cruise	389.3	51.1	47.3	157x(%S)	17
Slow	337.5	56.7	59	157x(%S)	17
500 - 1000 Horsepower					
Full	300	24	61	157x(%S)	17
Cruise	300	17.1	80.9	157x(%S)	17
Slow	167.2	16.8	62.2	157x(%S)	17
1000 - 1500 Horsepower					
Full	300	24	61	157x(%S)	17
Cruise	300	24	61	157x(%S)	17
Slow	300	24	61	157x(%S)	17
1500 - 2000 Horsepower					
Full	472	16.8	237.7	157x(%S)	17
Cruise	623.1	24	44.6	157x(%S)	17
Slow	371.3	24	122.4	157x(%S)	17
2000+ Horsepower					
Full	399.6	21.3	95.9	157x(%S)	17
Cruise	391.7	16.8	78.3	157x(%S)	17
Slow	419.6	22.6	59.8	157x(%S)	17
GASOLINE ENGINES	Grams per Brake Horsepower Hour				
Exhaust Emissions - All HP Ratings	5.16	6.68	199	0.268	0.327
Evaporative Emissions		62.0	Grams/Hr		
Crankcase Blowby		38.3	Grams/Hr		

Notes: 1) Average sulfur concentration for marine diesel fuel = 0.8 percent.

Sources:
1) U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, 1985.
2) U.S. Department of Transportation, Port Vessel Emissions Model, 1986.
3) California Air Resources Board, Report to the California Legislature on Air pollutant Emissions from Marine Vessels.

Attachment 8: LDV Stock Model

Fuel Economy, Vehicle Choice, and Changing Demographics

This attachment documents the methodology used to forecast the light truck (e.g. pickup trucks, sport utility vehicles) share of total light duty vehicle sales in the NEMS Transportation model. Given the marked difference in fuel economy standards for cars and light trucks this share directly affects both the forecast level of oil consumption and the level of carbon emissions. More generally, the presentation highlights the importance of considering structural shifts in developing long-term energy forecasts.

Background

Short-term (one to two years) forecasts assume that past trends in energy use and past relationships between economic and demographic factors and energy use will continue in the near term. They implicitly assume that structural changes are relatively unimportant as a cause of forecast error compared to errors introduced by uncertainty in estimates of forecasts of variables such as economic growth and energy prices. Those who tinker with long-term energy forecasts don't have this luxury. Certain physical assumptions may be accepted without further consideration (e.g. first law of thermodynamics, heating-degree days in a "normal" year in Southwest Census region). However, the longer the time horizon of the forecast is the more important it is to scrutinize assumptions that remain implicit in short-term forecasting. For example, to develop short-term forecasts of electricity use in buildings it isn't necessary to disaggregate this use by type and efficiency of equipment; it is reasonable to assume that changes in these factors are not an important source of uncertainty. This same assumption would be entirely inappropriate in a methodology used to forecast long-term building sector electricity use. The Energy Information Administration's A*nnual Energy Outlook 1996* provides energy forecasts through 2015. Within this time frame most of the electricity-using equipment now in buildings will be replaced and even the currently known menu of replacement choices vary considerably in energy efficiency.

This attachment scrutinizes a single variable in the NEMS Transportation model--the share of light trucks relative to total light-duty vehicle annual sales. It compares estimates of the light truck sales share based on extrapolating past trends to an approach that makes explicit assumptions concerning the impact future demographic changes will have on vehicle choice decisions. We know with a fair degree of certainty that as the generation of "baby boomers" reach age 55, the share of the population under the age of 55 will decrease sharply from the share maintained for many decades. We also know the age distribution of current truck purchasers. The methodology described provides forecasts of the light truck share based on knowledge of an aging population. The methodology does not address the question raised in the subtitle of this paper. To the extent that the population over age 55 in 2015 behave differently from the current over 55 population in terms of their vehicle purchases, the forecasts either under or over estimate the level of new light truck sales.

Methodology

Information on the characteristics of light truck buyers were obtained from the *1989 Buyers of New Compact Trucks, Summary Report*, published by Newsweek. Light trucks are divided into two types, pickup and sport utility.

Table E-83: Truck Buyer Characteristics

	Pickup	Sport Utility
Total	53%	47%
Male	88%	73%
Female	12%	27%
<19	3%	1%
20-24	13%	7%
25-29	13%	15%
30-34	11%	15%
35-39	13%	17%
40-44	12%	16%
45-49	9%	11%
50-54	7%	8%
55-59	6%	5%
60-64	5%	3%
>65	8%	2%

The first step in the methodology used was to aggregate the data across the type of truck, in order to determine a combined age and sex distribution among truck purchasers.

Let: P_{Type} = the percentage of total light truck purchases of a given type.

$P_{Sex,Type}$ = the percentage of each type purchased by a given sex.

$P_{Age,Type}$ = the percentage of each type purchased by a given age group.

Then, aggregating across truck types:

$$P_{SEX,AGE} = \sum_{TYPE} P_{TYPE} \cdot P_{SEX,TYPE} \cdot P_{AGE,TYPE}$$

as displayed below. A summation across sex within each age group provides the age distribution of light truck purchasers, depicted in the chart below.

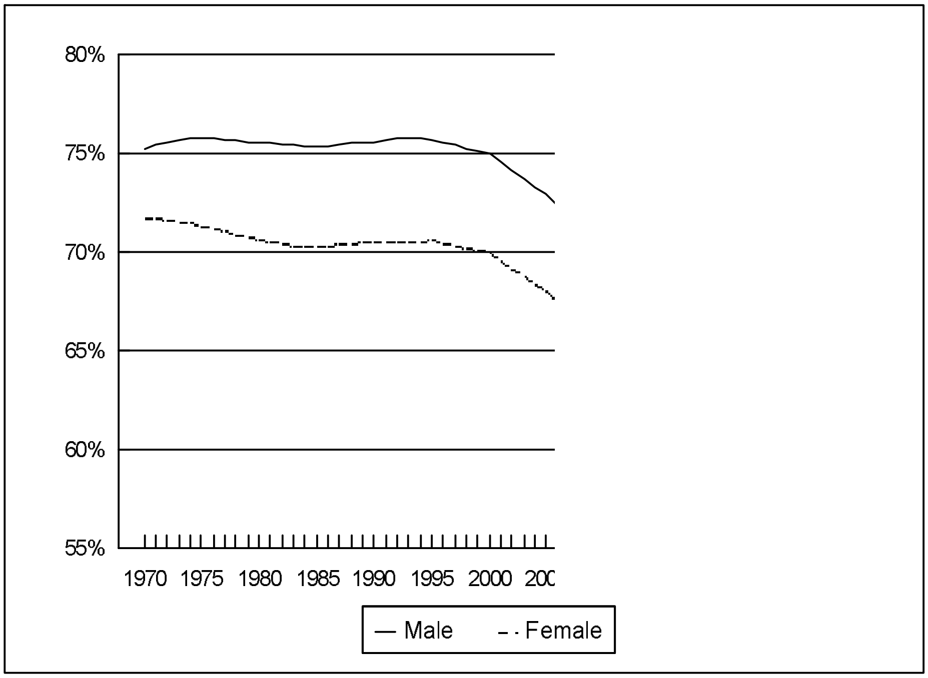
Table E-84: Light Duty Vehicle Purchases by Age and Sex, 1989

Overall LDT Purchases				
Age Group	**Male**	**Female**	**Total**	**Cumulative**
<19	1.7%	0.3%	2.1%	2.1%
20-24	8.5%	1.7%	10.2%	12.2%
25-29	11.2%	2.7%	13.9%	26.2%
30-34	10.3%	2.6%	12.9%	39.1%
35-39	11.9%	3.0%	14.9%	53.9%
40-44	11.1%	2.8%	13.9%	67.8%
45-49	8.0%	2.0%	9.9%	77.8%
50-54	6.0%	1.5%	7.5%	85.2%
55-59	4.5%	1.0%	5.5%	90.8%
60-64	3.4%	0.7%	4.1%	94.8%
>65	4.4%	0.8%	5.2%	100.0%
Total	81.0%	19.1%	100.0%	

Based on the cumulative percentages, approximately 85 percent of all light truck purchases are made by people under 55 years old. Of this group approximately 81 percent are men and 19 percent are women (Table E-91).

A weighted average of the share of the driving age population under 55 years is used as a proxy to measure the demographic impact of an aging population on future truck purchase trends. Note the methodology developed here assumes that people over age 55 will continue to represent only about 15 percent of the light truck purchasing market (Table E-91). Given this assumption, as the proportion of the population under age 55 falls after 2000, truck sales will as a proportion of light-duty vehicle sales will stabilize. In 2015, the unadjusted light truck market share is 49 percent compared to a population-adjusted share of 43 percent.

Figure E-3: Proportion of Population Under 55 Years



The specific methodology used in *AEO96* to develop a demographic index to dampen future truck sales is detailed below. It is certainly not the only index that could have been developed, however, under the assumption that "Grandma will not choose to drive a pick up truck" any approach would dampen light truck sales beyond 2000.

Weighted Population Index

Since the cumulative total (Table E-91) indicates that people under the age of 55 are responsible for 85 percent of all light truck purchases, declines in this share of the population is used as a moderating influence relative to a trend based estimate of light truck sales based on extrapolating recent history. The population index is weighted by the male/female distribution (Table E-91) of truck buyers, as follows:

Let $P_{Sex,\ Age}$ = the fraction of all LDT buyers of a given sex and age group

$\Pi_{Sex,\ Age<55,\ T}$ = the percentage of the population under the age of 55, by sex, in year T

The weighted share of the population under the age of 55 is then:

$$P{<}55_T = \sum_{SEX} \left[\Pi_{SEX,\ AGE<55,\ T} \cdot \left(\sum_{AGE} P_{SEX,\ AGE} \right) \right]$$

This share is subsequently indexed (1990 = 1.0). Index values are included in the data provided with this paper. The effect of the aging of the "baby boomers" is dramatic. The aging population has nearly a 15 percent dampening effect on new truck sales relative to a straightforward extrapolation estimate based on recent trends.

Extrapolation of Recent Trends

The unadjusted share of total LDV purchases accounted for by trucks is extrapolated using the 1982 and 1992 values as anchor points, and an assumed maximum value. The functional form of the curve is as follows:

$$\textit{Light Truck Share} = \mathbf{1998}\ \textit{Share} + (\textit{MaxDiff} * (1 - e^{k*(Year-1998)}))$$

where:

1998 Share =	Historical light truck sales share in 1998 = .436
Maxdiff =	difference between 1998 share and 50% = .064
k =	time coefficient for 97% of the distance to 50 percent of sales in 2020 = -.1611
Year =	current year greater than 1998

Fuel Price Adjustments

The following section describes the fuel price methodology used to adjust the light truck sales share estimate detailed in the previous section based on demographics. Because the light truck sales proportion of light-duty sales was exogenously determined offline and was originally based only on demographics, the light truck sales share was altered to reflect situations where high fuel prices would provide incentive for consumers to switch back from light trucks toward cars. It was assumed that the light truck sales share at the very most would decline by a 8% sales share relative to the original light truck sales share estimated by demographics. When fuel prices exceed \$8.00/mmbtu up to \$14.90/mmbtu, the light truck share will fall by 8% below it's original value or 38% light truck sales share. The 38% light truck sales share corresponds to the 1993 sales level. The highest historical level of light trucks before the light truck sales trend escalated in 1990 was approximately 32% in 1989. Hypothetically, the light truck sales share could fall to pre-1990 levels of 32%, but this was deemed to be unlikely because manufacturers currently have dropped most of their station wagons built off of sedan carlines thereby limiting the potential to fall to pre-1990 levels. All fuel prices between \$8.00/mmbtu and \$14.90/mmbtu require scaling the total 8% sales share adjustment to that proportion of the difference between \$8.00/mmbtu and \$14.90/mmbtu (or

$6.90/mmbtu). The following equation was used:

$$CARLTSHRCS = CARLTSHR-(LTDIFF*SCALER)$$

where:

$$SCALER=\frac{(TPMGTR-TPMGLO)}{(TPMGHI-TPMGLO)}$$

where:

CARLTSHRCS =	Adjusted car and light truck sales share for high fuel prices
CARLTSHR =	Car and light truck sales share based on demographics
LTDIFF =	Total sales share decline
SCALER =	Proportion of total fuel price rise relative to highest fuel price when full value of LTDIFF is applied
TPMGTR =	Current gasoline price
TPMGLO=	Lowest fuel price at which adjustments will be applied
TPMGHI=	Fuel price at which total LTDIFF adjustments will be applied

NEMS Transportation Model Light-Duty Vehicle Vintaging Extended to 20 Years

Introduction

The vehicle stock model within NEMS contains vehicle stock for passenger cars and light trucks by fuel type (gasoline and diesel) by vehicle vintage year. Previously, NEMS used stock data for individual vintage years of 1 through 9, along with vintages of 10 years or more grouped together. The stock model was extended to represent vehicle stock for individual vintages of 1 through 19 and as a group for vintages of 20 years or greater. Total vehicle-miles of travel (VMT) estimates and corporate average fuel efficiency (CAFE) standards by vehicle type were also extended back to twenty years.

Procedure

This section summarizes the fundamental procedure used to generate the extended stock model data. The general procedure for developing the stock estimates, along with the original data sources used in the model, is provided in the following paragraphs.

Step 1. Determine vehicle stock by vehicle type and by fuel type by vintage for vintages 1-19 and 20 and greater for calendar years 1990-96.

The first step in extending the NEMS vehicle stock model was to determine the total vehicle stock by vehicle type and by fuel type for individual vintages 1-19 and for vintages 20 years or greater as a group. Vehicle registration data from The Polk Company's National Vehicle Population Profile (NVPP) database was used as a starting point. Polk estimates registration data by vehicle type and by fuel type by individual vintage for up to 14 or 20-some years, depending upon the calendar year. Stock for subsequent vintages are summed as a group. For example, for calendar year 1990, Polk provides gasoline-powered passenger car stock for individual vintages though 14 years of age. Vehicles 15 years old or more are all summed together and given as vintage "15+".[112]

To coincide with NEMS vehicle and fuel categories, Polk data was entered into four vehicle stock tables: (1) passenger cars - gasoline, (2) passenger cars - diesel, (3) light trucks - gasoline, and (4) light trucks - diesel.

Since stock calculations for all individual vintages between 1 and 19 (0 and 18 in Polk's database)

[112]It should be noted that NEMS and Polk use different numbering conventions for vehicle age, or vintage. NEMS considers the first year a vehicle is in operation as year 1, while Polk, and other sources used in extending the stock model, consider the first year of operation as year 0. The reader should remember this when comparing this document with the original data sources.

are not available for all calendar years, vehicle scrappage rates were applied to stock estimates for previous calendar years. For example, to calculate the vehicle stock for 16-year-old vehicles in 1993, the scrappage rate for 16-year-old vehicles was applied to the estimate of the number of 15-year-old vehicles in 1992. Separate scrappage rates were used for passenger cars and light trucks, and different scrappage rates were used for passenger cars sold before 1990 and for those sold in 1990 or later. (Davis, S.C. 1998. *Transportation Energy Data Book: Edition 18.* Oak Ridge National Laboratory, Oak Ridge, Tennessee, tables 5.9 and 5.10.)

Step 2. Determine the stock for light trucks 8,500 lbs or less GVWR.

It should be noted that the Polk light truck registration estimates are for light trucks 10,000 lbs or less GVWR, while the NEMS model requires stock estimates for light trucks 8,500 lbs or less GVWR. Therefore, to make the stock model consistent with NEMS, it was necessary to estimate how many of the light trucks in the Polk estimates are 8,500 lbs or less GVWR. This was accomplished by taking annual sales data for these two groups of trucks and applying the proportion of 8,500-lb-or-less trucks to the Polk estimates. For example, the sales ratio for 1990 light trucks would be applied to the 1-year vintage trucks in 1990, the 2-year vintage trucks in 1991, the 3-year vintage trucks in 1992, and so forth. This method assumes that trucks 8,500 lbs or less GVWR and 10,000 lbs or less GVWR are scrapped at the same rate and that diesel and gasoline trucks are scrapped at the same rate. The source for retail sales of light trucks 10,000 lbs or less GVWR is the American Automotive Manufacturer's Association (*Motor Vehicle Facts & Figures 1997*, Detroit, Michigan). The source for retail sales of light trucks 8,500 lbs or less GVWR is the USDOT National Highway Traffic Safety Administration (John Finneran, personal communication, 20 August 1998).

Step 3. Determine the stock of vehicles used in fleets.

NEMS handles fleet vehicles separately from the rest of the vehicle stock. The light-duty vehicle stock estimates for fleet and personal vehicles are treated differently in NEMS. Therefore, in order to be consistent with the NEMS model, fleet vehicles had to be subtracted from the total light-duty vehicle extended stock model in order to arrive at personal vehicle stock estimates.

The first step in this process was to determine the fleet vehicle stock in a manner consistent with NEMS. NEMS assumes that vehicles entering the fleet represent 23.70% of new car retail sales and 28.57% of light truck retail sales (see table 1). New vehicle retail sales are fairly representative of the 1-year vintage vehicle stock. Therefore, a table of fleet vehicles' proportion of total new vehicle retail sales for both cars and light trucks was created. This data was used as a surrogate for 1-year vintage vehicle stock.

The NEMS model uses scrappage curves for three fleet types: (1) business, (2) government, and (3) utility. Therefore, it was necessary to model these fleet types separately. Vehicle stocks were assigned to each of these fleets using the fleet type shares (i.e., shares of new fleet vehicle retail sales) used in NEMS. The fleet vehicle shares by fleet type (listed in table 1 below) were multiplied by the new vehicle retail sales for each year to determine the 1-year vintage stock for each calendar year.

Table 1. Parameters used in estimating fleet vehicle stock.

Vehicle Type	Share of Vehicle-Type Retail Sales	Fleet Type	Share of Fleet Sales	Maximum Years in Fleet
Passenger Car	0.2370	Business	0.8739	5
		Gov't	0.0742	6
		Utility	0.0519	7
Light Truck	0.2857	Business	0.835	6
		Gov't	0.141	7
		Utility	0.024	6

The second step was to determine the stock for vintages other than the first year using the same scrappage conventions used in NEMS. NEMS survival rates for fleet vehicles were used to determine the rest of the fleet stock. These survival rates represent the proportion of vehicles of a given age that are likely to still be a part of the fleet as of a given year.

NEMS uses two different survival rates for fleet vehicles—one for the business fleet and one for the government and utility fleets. Furthermore, NEMS assumes that the time a vehicle stays within a fleet before returning to regular stock is dependent upon the vehicle type and fleet type (see table 1). Therefore, the fleet stock was determined by applying the appropriate scrappage rates to the passenger cars and light trucks in each fleet, and removing these vehicles from the fleet once they had reached the maximum fleet vehicle age allowed within NEMS.

After the stock for each vehicle and fleet type was estimated. The fleet stock was aggregated by vehicle type, creating a fleet passenger car stock table and a fleet light truck stock table.

Step 4. *Subtract the fleet vehicles from the passenger car and light truck stock models.*

The final step in creating the extended vehicle stock model for NEMS was to subtract the fleet vehicle estimates from the stock model for the appropriate vintages. However, in subtracting the fleet models, we needed to resolve two final deficiencies/discrepancies in the data: (1) the fleet vehicle estimates were not divided into gasoline- and diesel-powered vehicles, and (2) the time periods covered by 1-year stock estimates in Polk's NVPP database—Polk considers these 0-year estimates—and new vehicle retail sales estimates by AAMA are not consistent.

In subtracting fleet vehicles from the rest of the vehicle stock, it is assumed that, for passenger cars and light trucks, the proportions of gasoline and diesel vehicles by vintage and vehicle type in each fleet is the same as in the overall stock. Therefore, fleet vehicles are subtracted from the rest of the stock as follows:

$$Non\text{-}Fleet\ Veh\ Stock_{v,f,a} = Total\ Veh\ Stock_{v,f,a} - \left[\left(\frac{Total\ Veh\ Stock_{v,f,a}}{\sum_f Total\ Veh\ Stock_{v,a}}\right) \times Fleet\ Veh\ Stock_{v,a}\right]$$

where

v = *vehicle type*
f = *fuel type*
a = *vehicle age or vintage*

As mentioned previously, the time periods covered by 1-year stock estimated by Polk and new vehicle retail sales estimated by AAMA are not consistent. Polk's NVPP data represents a "snapshot" of registered vehicles as of July 1 of that calendar year. AAMA retail sales data represent sales during the entire calendar year. Thus, Polk first year stock estimate is always underestimated since approximately a half year's worth of new car registrations are not included in the estimate. So, if fleet stock estimated from a full year's sales were subtracted from Polk's 1-year vintage vehicle stock, the resulting vehicle stock for non-fleet vehicles would be underestimated. Therefore, the Polk 1-year vehicle stock estimates are used as a surrogate for new vehicle retail sales, and the fleet proportion of retail sales is applied to the surrogate. As such, fleet vehicles are subtracted from all 1-year stock estimates according to the following equation:

$$Non\text{-}Fleet\ Veh\ Stock_{v,f,a} = Tot\ Veh\ Stock_{v,f,a} - \left[\left(\frac{Tot\ Veh\ Stock_{v,f,a}}{\sum_f Tot\ Veh\ Stock_{v,a}}\right) \times \left(Tot\ Veh\ Stock_{v,a} \times Fleet\ Share\ of\ Retail\ Sales_{v}\right)\right]$$

where

v = *vehicle type*
f = *fuel type*
a = *vehicle age or vintage*

Step 5. Arrange stock data in the format used by NEMS.

Finally, the 1990-96 calendar year stock data for gasoline and diesel vehicles was placed in a table formatted to match that used by NEMS. The data was also converted to units consistent with NEMS.

References

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Attachment 9: Freight Truck Stock Model

Freight Truck Technology Characteristics

Assumptions:

Key assumptions are described below.

Non-Engine Technologies[113]

The fuel economy improvement potential of non-engine technologies was developed primarily from data on heavy-truck technologies, and adjusted considering the lower-speed duty-cycle of medium-duty trucks (a more comprehensive study would model each use within the truck classes to estimate detailed impact of duty cycle on fuel economy). The improved non-engine technologies identified are: (1) low-resistance tires (super-singles), (2) high-efficiency transmission, (3) synthetic gear lubricants; (4) advanced aerodynamic drag reduction, and (5) lightweight materials.

Super single tires improve fuel economy by about 2-3% (Cuenca et al. 1999; DOE 1997). We assume 6 tires replace 12 at an incremental cost of $30-40 per original tire for the heavy-duty trucks, replaced every 60,000 miles, and 2 tires replace 4 tires for the medium-duty trucks, replaced every 50,000 miles (Bridgestone 1996). We assume they can be retrofit onto the existing truck fleet.

High efficiency transmission technologies are aimed at reducing mechanical losses in these components by 25% (DOE 1997), resulting in a fuel economy improvement of about 1-4% (Cuenca et al. 1999; DOE 1997). Actual efficiency improvements are a function of duty cycle, with higher efficiency improvement possible during lower speeds (An et al. 1999). We assume the minimum efficiency gain on medium-duty trucks, many of which are used in low-speed, congested conditions, is double that of the heavy-duty trucks, which travel mostly at high speeds. We assume high-efficiency transmission benefits are not applicable for hybrid medium duty trucks because the hybrid configuration greatly improves the efficiency of the existing drivetrain.

We assume synthetic gear lubricants (affecting the drivetrain, except the engine[114]) improve fuel economy by 2-3% (Cuenca et al. 1999). We assume the incremental lubricant cost is $40-$60 per change, and the period between changes is 100,000. We assume synthetic lubricants can be used on the existing fleet.

[113] Technologies that reduce parasitic losses.

[114] Improvements in engine lubrication are included under advanced engines.

The effects of aerodynamic drag reduction is a strong function of vehicle speed.[115] Heavy-duty trucks classed as long-haul travel mostly at highway speeds, 65 mph, while medium-duty trucks travel mostly at lower speeds (approximately 45 mph). Therefore, the benefits of reduced aerodynamic drag is significant for most heavy-duty trucks.[116] We assume advanced drag reduction treatments can be retrofit onto the existing fleet. For heavy-duty trucks, we assume drag reduction improves fuel economy by 8-10% (Cuenca et al. 1999, DOE 1997), and for medium-duty trucks, fuel economy is improved by 4-5%. We assume costs of drag reduction range from $500-$1000 for heavy-duty trucks, and proportionately ($250-$500) for medium trucks (Cuenca et al. 1999).

Lightweight materials allow weight-limited trucks to increase carrying capacity for those (thereby reducing the number of trucks for a given tonnage of freight hauled), and allow fuel economy improvements for those trucks that "cube out," i.e., are volume limited. Assuming the weight of an unloaded tractor-trailer is 26,000 lbs, and the use of aluminum and plastics reduce the weight by 2,000-2,500 lbs, the loaded tractor trailer weight reduction is 2.5-3.1%. Assuming a 0.66% increase in mpg for each 1% of weight reduced (based on passenger car data--truck data is not available), fuel economy increases by 1.5-2%.

Diesel Engine Technologies

This category, applicable to all diesel-engined trucks, includes electronic engine control and an "advanced" engine. Electronic engine control refers to electronic fuel injection (e.g. electronic unit injectors and common rail injectors), electronic unit pump and electronic distributor pump systems (Browning 1997). These systems are already commercial, some form of electronic engine control has been available since 1990 (Cuenca et al. 1999). Fuel economy gains around 4% are possible for both heavy-duty and medium-duty trucks (Cuenca et al. 1999). Incremental costs are estimated to be $800-1000. (This estimate is higher than the hardware estimates by EPA of $467 as reported by Browning (1997). We assume additional technology is used beyond what is required to meet the 2004 emission standards.) Market penetration is expected to be high--almost all engines (91%) are expected to have electronic engine controls by 2004 because of the new emission standards (Browning 1997).

The "advanced" engine is a term used here to describe the technical targets, developed by the U.S. Department of Energy with industry input, for the next-generation, low emission, high efficiency heavy-duty diesel engine (DOE 1997). A fuel economy improvement of 10% over today's engine is possible with the following (percent improvement in parentheses): (1) higher peak cylinder pressure

[115] Power needed to overcome air resistance varies as the cube of speed.

[116] The clear exception in this class is refuse haulers, averaging 10 mph or less. A more complete study would differentiate among uses within the heavy-duty truck class.

(4%); (2) improved combustion technology (1%); (3) reduced friction (1%); (4) improved thermal management (2%); and (5) higher turbocharger efficiency (2%). We assume the advanced engine is sold as a package because some, if not all of the technologies will be required to meet 2004 emission standards. While the technologies are available now, we assume a *net reduction* in fuel consumption is possible only after further improvements in performance and emission control technology. We select the year 2009 as the target for these improvements to become commercial (this year has been discussed as the start of the next-level of diesel emission control) (Cuenca et al. 1999). We assume the same gains are possible for medium-duty truck engines. We assume incremental costs for the advanced engine technologies ranges from $800-$1000 for heavy- and medium-duty engines (Cuenca et al. 1999).

Heavy-Duty Truck Diesel Engines

Turbocompounding is an additional technology primarily suited for heavy-duty trucks. This will improve fuel economy an additional 5% compared to an advanced engine, described above (adapted from DOE 1997). Turbocompounding is available today, but it is uneconomic. We estimate future incremental costs over the advanced engine to range from $1700 to $2000, and we assume it will become commercial about 5 years after the advanced engine, or 2014.

Medium-Duty Truck Diesel Engines

Hybrid powertrain technology is suitable for medium-duty trucks operating on diesel fuel or gasoline (gasoline application described below). A fuel economy gain of 60% is possible based on modeling performed by Argonne National Laboratory on a Ford E350 Navistar turbocharged direct-injection diesel engine based on the average of eight central business district and urban driving cycles (An et al. 1999). An incremental cost of $4000-$6000 is estimated based on An et al. (1999) and Cuenca et al. (1999) for high-volume production. Market introduction is estimated to be 2006, which assumes manufacturers gain significant experience beforehand in passenger vehicles, expected to be introduced in the U.S. in the spring of 2000.

Heavy-Duty Truck Gasoline Engines

Port-injection is expected to be required to meet 2004 emission standards. An additional benefit is a 1-2% increase in fuel economy. An incremental cost of $200-$300 is anticipated. Market introduction was 1998, and we expect maximum market penetration in 2004 due to emission standards; payback analysis is not necessary for this technology.

Medium-Duty Truck Gasoline Engines

Hybrid powertrain technology is expected to improve fuel economy by about 70%, based on the An et al. (1999) study of a GMC Vortec Gasoline V-8 engine. The fuel economy improvement represents the average over eight central business district and urban driving cycles. Incremental cost is expected to be the same as the medium-duty diesel engine truck case, above ($4000-$6000).

Alternative Fuels: Natural Gas

Heavy-Duty Trucks

Liquefied natural gas (LNG) is the expected form of natural gas fuel for heavy-duty trucks because its energy density is much greater than in the compressed form, allowing farther travel between fueling. Compared to a gasoline engine, fuel economy is the same or at best about 2% better (assuming an optimized, lean-burn engine). We assume the engine incremental cost (compared to a diesel engine) is $15000 and tank cost is $35,000, assuming a range of 1200 mi, typical for a long-haul tractor-trailer) (GRI 1994). We feel the alternative engine costs are based on current, limited production. For a lower bound, we assume engine costs are reduced by ½, to $7500. Obviously, LNG is not economic compared to conventional fuels. A reasonable assumption is that the LNG trucks continue to penetrate the market based on government incentives. Heavy-duty LNG trucks would most likely replace heavy-duty gasoline trucks.

Medium-Duty Trucks

Compressed natural gas (CNG) is expected for medium-duty trucks because most travel relatively short distances during the working day and return to a central station where they can be refueled at night. Fuel economy improvement relative to its gasoline-fueled counterpart can be up to 2% because of leaner operation (DOE 1994). Incremental engine costs are estimated to be $900 (Hartmann 1994) to $3000 (GRI 1994) and incremental fuel tank costs are estimated to be $125/gallon gasoline equivalent for composite tanks (or $5000 for a 40 gallon tank) (DOE 1994).(Composite tanks are assumed here because heavier metal tanks would significantly add to vehicle weight, thereby reducing performance and hauling capacity. Composite tanks cost considerably more than conventional metal tanks.) Miscellaneous parts and conversion is expected to cost $4000 (GRI 1994). Total incremental costs are estimated to range between $9,900 and $12,000. Like LNG, CNG is not economic compared to conventional fuels. A reasonable assumption is that the CNG trucks continue to penetrate the market, replacing gasoline trucks, as a result of government incentives, not economics.

Alternative Fuels: LPG

Heavy-Duty Trucks

Liquefied petroleum gas (LPG) fuel is expected to improve fuel economy by up to 3% compared to gasoline (DOE 1994), because of leaner operation. Incremental costs are expected to range from $7500-$15000 for the engine (the same incremental cost as the LNG engine (GRI 1994) and about $4000 for the tank (tank cost estimated to be $6/gallon gasoline equivalent based on Montcour 1994). Total incremental cost is $11500-$19000. A reasonable assumption is that the LPG trucks continue to penetrate the market based on government incentives. Heavy-duty LPG trucks would most likely replace heavy-duty gasoline trucks.

Medium-Duty Trucks

Performance of LPG in medium-duty trucks is expected to be the same as its performance in heavy-duty trucks (3% improvement in fuel economy relative to gasoline). Incremental costs are estimated to be $700 (Moreno and Bailey 1989) to $3000 for the engine (GRI 1994), and $4000 for the fuel tank, hardware, and labor (GRI estimate (1994), adjusted for 40 gal gasoline equivalent tank). (Note Montcour (1994) estimates an LPG tank to cost $6/gallon gasoline equivalent, so much of the cost is associated with hardware and labor.) A reasonable assumption is that the LPG trucks continue to penetrate the market based on government incentives. Medium-duty LPG trucks would most likely replace medium-duty gasoline trucks

Table E-85: Freight Truck Technology Characteristics[117]

	Fuel Economy Improvement		Maximum Penetration (%)		Introduction Yr		Capital Cost	
	Mediu	Large	Mediu	Large	Mediu	Large	Medium	Large
Existing Technologies								
Advanced tires: Radials	2%	2%	70%	70%			$150	$450
Drag reduction	3%	5%	65%	65%			$500	$1,000
New Technologies								
Advanced transmission	2%	1%	40%	40%	2001	2001	$2,500	$2,500
Lightweight materials	1%	1%	30%	30%	2002	2002	$3,000	$3,000
Synthetic gear lube	2%	2%	60%	60%	2001	2001	$40	$60
Advanced tires: Low Resistance	4%	4%	70%	70%	2001	2001	$300	$900
Advanced drag reduction	4%	7%	65%	65%	2001	2002	$600	$1,200
Electronic engine control	4%	4%	95%	95%	2001	2001	$1000	$1,000
Advanced engine	9%	9%	90%	90%	2009	2009	$1000	$1,000
Turbocompounding	0%	5%	0%	90%	N/a	2001	N/a	$2,000
Hybrid powertrain	54%	0%	20%	0%	2006	N/a	$6000	N/a
Port-injection	0%	1%	0%	100%	N/a	2001	N/a	$300

Source Argonne National Laboratories, Frank Stodolsky, Anant Vyas, Roy Cuenca. *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis*, Prepared for Energy Information Administration, Draft 8/6/99.

[117]Source Argonne National Laboratories, Frank Stodolsky, Anant Vyas, Roy Cuenca. *Heavy- and Medium-Duty Truck Fuel Economy and Market Penetration Analysis*, Prepared for Energy Information Administration Draft 8/6/99